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REVIEW AND COMPARISON OF SITE EVALUATION METHODS

JOHN R. JONES

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Review and Comparison of Site Evaluation Methods

by

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Review and Comparison of Site Evaluation Methods

John R. Jones

This review does not attempt to include every paper or recognize every school of site evaluation. The field was first outlined and then developed. The papers cited were selected mainly to illustrate concepts, methods, and results. For example, the principles of characterizing site by classifying the vegetation are covered by discussing the Finnish and related work. The Zurich-Montpellier and Russian schools are regarded as other means of classifying vegetation and are not discussed here, although work by their adherents is cited in other contexts. Emphasis has been on North American work, on European work that has been especially influential in North America, and on certain European work that provided insight into North American work.

The review is organized into three main sections, each followed by a summary. They are:

1. The site index approach.
2. Vegetation approaches.
3. Environmental approaches.

Some studies have combined approaches. These are discussed where they contribute to the development of the subject.

The Site Index Approach

A common method of evaluating site in even-aged forests or those with an even-aged overstory has been site index—the average height of sample canopy trees at a selected index age, such as 50 years.

A stand of index age is seldom encountered. Assume a stand younger than the index age. What is its site index? That is, how tall will it be when it reaches the index age? To estimate site index, the age of the stand and the average height of several dominant trees are determined. In some early systems, the average of a sample from both the dominant and codominant crown classes was used—for example, that of McArdle (1930) for Douglas-fir[2] in the Pacific Northwest. The point at which the age and height ordinates intersect are found on a graph, and the site index value estimated by interpolation between two site index curves. The procedure is the same for stands older than the index age. Figure 1 shows site index curves for Engelmann spruce (Alexander 1967).

Site index curves describe the course of height growth of hypothetical trees of specified site indexes. Sometimes height-age tables designed from site index curves are used instead of the curves themselves.

According to Cajander (1926), Huber used site index in Germany as early as 1824. Its use spread

[2]*Common and scientific names of plants, insects, and diseases mentioned are listed on p. 27.*

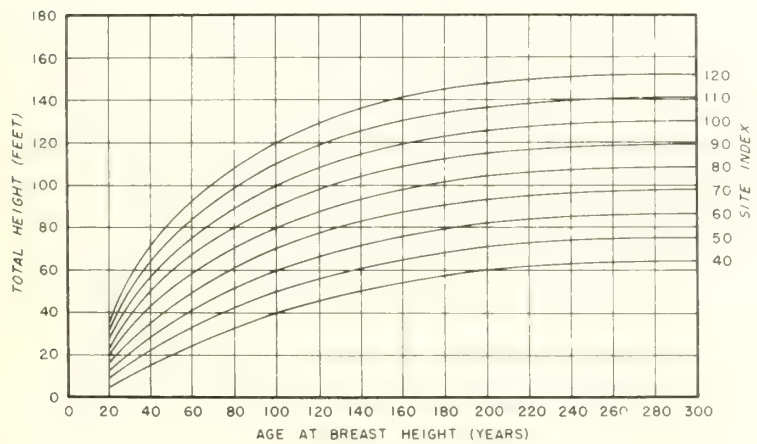

Figure 1.- Engelmann spruce site index curves for the central Rocky Mountains (Alexander 1967).

to Scandinavia (Jonson 1914) and to the United States (Sterrett 1914). Not long after its introduction into the United States, the concept was discussed in a series of articles (Parker 1916, Roth 1916, 1918, Spring 1917, Watson 1917, Bates 1918, especially Frothingham 1918), and compared with the volume-age relationship, vegetation types, and environmental factors as possible alternative indexes. The height-age relationship was deemed much superior.

Site index curves can be developed from height growth records from permanent plots, where these are available (Spurr 1952, 1956). Mostly, however, they are based on the heights and ages of stands on many temporary sample plots. The range of age classes and of sites must be included in the sample. This is the approach described in American texts on forest mensuration from Chapman (1921) to Husch (1963).

For years the standard methods of curve construction in the United States were graphical anamorphosis as described by Bruce (1926), or the graphical method of Osborne and Schumacher (1935). In recent years the multiple regression of height on age and on site index has been used. The general procedure is similar to the earlier standard graphical methods except that the curve form is dictated by a selected equation form, and the curves are fitted by the method of least squares.

Construction of a set of site index curves by the above methods assumes that (1) all the factor combinations sampled produced height-age curves which are harmonic, that is, which are proportioned to each other throughout the ages of the stands, and (2) the site index given by any stand will not change during the life of that stand. Weaknesses in these assumptions have been discussed by Cajander (1926), Bull (1931), Spurr (1952,1956), Carmean (1956), and Vincent (1961).

Errors from the first assumption should be reduced by the use of "natural" site index curves. According to their description by Cajander (1926), the pioneering curves of Huber were natural site index curves. Bull (1931) introduced them to the United States, and their principle is well illustrated in the construction of his site index curves for planted red pine in Connecticut. He described the actual course of height growth for each sample tree by measuring the height of each annual branch whorl. The height-age data for all trees in a single site index class were then combined to form a site index curve for that class. No curve depended on data from any other class.

The same principle has been followed where whorl counts are not possible; basic data are ring counts at measured intervals along the boles of felled trees—that is "stem analysis." This was Huber's method (Cajander 1926). Jameson (1965) illustrated serious discrepancies between standard site index curves for jack pine in Saskatchewan and height-age curves based on stem analysis.

The advantage of natural site index curves is limited, however, because among plots with virtually identical heights at index age, tree curves on one plot may differ considerably from tree curves on another plot, at least for aspen in the Rocky Mountains (Jones 1967a), lodgepole pine,[3] and for birch in Norway (Persson 1959). This diversity of curve forms for plots of similar height at index age results in a plot giving different estimates of site index at different ages, regardless of whether the class curve is "natural" or derived by standard anamorphic techniques.

Williamson (1963) demonstrated moderate site index changes in 30- to 50-year height records on Douglas-fir growth plots. Watt (1960) found only unimportant changes in site index on western white pine plots.

Diversity in the forms of height growth curves presumably is caused by different combinations of site factors and changes in the identity of limiting factors during stand development. These changes may result, for example, in rapid juvenile growth and early growth deterioration on some sites, while on others juvenile growth may be moderate but may slow little at maturity. Genetic differences undoubtedly contribute in some degree to curve-form diversity in most if not all species. Contrasting habitats select for populations that will differ genetically according to the type and severity of selection and the nature of the response mechanism. In the case of bigtooth aspen, and of quaking aspen in the Rocky Mountains, genetic differences between clones are important (Zahner and Crawford 1965; Jones 1967b).

Ilvessalo (1927, 1937) presented height-age curves for Scots pine in Finland, for different site-types as defined by ground vegetation. The curve forms differed, sometimes considerably, on different site types. The same was true for ponderosa pine on different site types in the northern Rocky Moun-

[3] *Unpublished data on file in the spruce-fir and lodgepole pine project, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.*

tains (Daubenmire 1961). Carmean (1956) found that, for Douglas-fir on different soils in southwestern Washington, two stands with similar heights at index age 100 may have differed in height at age 20 by 2:1, the differences remaining very large even at age 50. As a result, site index estimates may err greatly.

Carmean (1956), Beck (1962), Zahner (1962), and Van Eck and Whiteside (1963) developed separate sets of site index curves for different soil or landform categories. This promises to reduce errors from both of the assumptions discussed: that height-age curves are harmonic and that site index remains constant as a stand ages. It actually amounts to superimposing a site index classification on an environmental classification—it could also be superimposed on a vegetational classification—and may be worthwhile where curve-form variability is sufficient.

Ward et al. (1965) suggested bypassing site index curves and formulas entirely by simply felling and sectioning sample trees on the site for which the index is desired. The site index is then read directly from the tree curves. This requires that the stand be at least as old as the index age, however, and is laborious and time consuming.

Juvenile growth rates are particularly apt to be poorly correlated with later growth rates and with site index. To reduce the effects, age is often based on the ring count at breast height, 4.5 feet, with or sometimes without (Jones 1966, Alexander 1967) the addition of the average number of years required by the species to reach 4.5 feet. In Denmark, age may be based on a count of rings as high as 2.3 meters (7.5 feet) above the ground (Løvengreen 1954). Walters et al. (1961) tried to refine this approach for some northwestern species by adding a variable number of years required to reach breast height, the number being based on crown class.

A mathematical approach to site index curve construction presented by Stage (1963) attempts to compensate for the effects of factors affecting seedlings and saplings. Ebeling (1959) was skeptical of highly refined systems of yield prediction, believing them more complicated than accurate.

A very basic assumption in site index is that height growth is not importantly influenced by stand density. Hopkins (1963), on the basis of a thinning study, pointed out that close spacing in young coastal Douglas-fir slowed height growth. In the northern Rocky Mountains, overstocking reduced the height growth of ponderosa pine enough that separate sets of site index curves have been made for different levels of stocking (Lynch 1958). The height growth of lodgepole pine in the Rocky Mountains is so strongly influenced by stocking over a wide range of densities (Smithers 1961, Holmes and Tackle 1962) that the height-age relationship alone is largely useless as an index of site. An extensive study has developed a system for this notoriously difficult species, incorporating height, age, and density (Alexander 1966, Alexander et al. 1967).

Some sites with similar height-growth potentials are very different from some others. In some cases they may differ appreciably in their stocking or longevity potentials, and therefore in their yield potential. This probably is not often an important factor, however, and seems to involve poor sites primarily.

Plantation cultivation may sometimes make a substantial difference in apparent site index (Wittenkamp and Wilde 1964). Correction factors may prove desirable where cultivation is planned.

For site index to give valid results, the site must bear an even-aged overstory where the heights of dominants have not been strongly influenced by stand history. For example, by partial cutting (Ilvessalo 1954) or by dwarf mistletoe infection (Shea 1964). Juvenile growth rates often are inconsistent with later rates. Therefore, young stands often give misleading estimates, and many site index curves are not even drawn below age 20. With some species, 20- or even 30-year-old stands give unreliable indexes (Warrack and Fraser 1955, Alexander 1966, Jones 1966).

For the above reasons or because of deforestation, many sites do not have stands suitable for determining site index. Also, the interest in yield potential is always related to a particular species. A site may be occupied by lodgepole pine, while the manager may wish to know its potential for Engelmann spruce. In some cases the site index for two species may be highly correlated (Doolittle 1958, Foster 1959, Olson and Della-Bianca 1959, Deitschman and Green 1965). Use of regressions to estimate the site index for one species from that for another seems risky, however, unless the regression is known to hold for the particular environmental combination involved.

The weaknesses in site index do not appear to be serious for most species in even-aged stands,

however. This is especially true if McGee and Clutter (1967) are right in stating that "there is seldom a need for site information that predicts future heights within ten feet" except for land acquisition and research purposes. In the United States, probably most foresters agree with Hodgkins (1956) and Vincent (1961) that site index is the best generally available indicator of relative yield potential where suitable stands are present. Certainly, site index often serves as the basic criterion in developing and testing alternative methods.

At the same time, site index is an index only to yield potential. It is not generally suited to other purposes—to characterizing sites for silvicultural prescription, for example. As an instance, one high index site may be readily reforested after fire or harvest, and another may be very difficult to reforest.

On the other hand, a habitat classification using an environmental approach has been developed for evaluating blister rust hazard to eastern white pine (Van Arsdel 1961). The susceptibility of subalpine fir to spruce budworm in the Canadian Rockies differed on different site-types as defined by ground vegetation (Shepherd 1959) as did ponderosa pine susceptibility to dwarf mistletoe in the northern Rockies (Daubenmire 1961). Comparable vegetation site-types have been widely used in prescribing forest regeneration methods in Europe (Kabzems 1951, Ilvessalo 1954, Arnborg 1960, Bärring 1965) and have been developed as a framework for general ecological studies in a section of the northern Rocky Mountains (Daubenmire 1952). The potential value of environmental site classification or ordination in studies of forest seed provenance and other studies of racial variation is clear from discussions by Dietrichson (1964), Callaham (1965), Silen (1965), and Benson et al. (1967).

Summarizing, even good site index curves used with proper regard for their limitations are a somewhat rough index to the productivity of sites. But it is the most direct method, and for most species in suitable stands, good site index curves probably are the best tool for evaluating productivity.

There remains a real need for the classification or ordination of sites based on environment or vegetation or both, not to replace the site index approach, but to supplement it and to some extent to refine it.

Vegetation Approaches

Under vegetation approaches I am including what many writers term the ecosystem approach, if the vegetation is used to define the ecosystem. The primary difference between the vegetation approach of Cajander (1926) and the ecosystem approach of Krajina (1960), for example, is the degree of emphasis given the environment in deciding upon the defining vegetaion.

The vegetation approach may take the form of classification or ordination.

Classification

Malmström (1949) cites two early Fennoscandian papers (Post 1862, Norrlin 1871) in which forest ecosystems were classified according to vegetation but with the explicit consideration of the habitats.

The approach received wide attention after Cajander (1909, 1926) subdivided the forest habitats of Finland into a complete set of forest site-types.[4] Each site-type was defined by the climax ground vegetation, using the polyclimax concept. Environmental similarity was a criterion in defining the site-types (Cajander 1926, Kalela 1960) and it was assumed that for forestry purposes all habitats falling within a single site-type could be considered effectively uniform.

By means of growth studies, yield prediction tables were developed for the different site-types (Ilvessalo 1927, 1937, Carbonnier 1954), and site-types have provided the frame of reference for forest management and research in Finland for many years (Ilvessalo 1954, Högnäs 1966, p. 94).

Coile (1938), an advocate of the soils approach to site evaluation, questioned whether the climax vegetation could be recognized after severe disturbance, and whether shallow-rooted ground vegetation would reflect the deeper lying soil conditions encountered by tree roots. Ilvessalo (1954) and Kujala

[4] *The Finnish "metsätyyppi," Swedish "skogstyp," and German "Waldtyp" translate literally to "forest type." In the American literature, however, the term forest type is widely used as a synonym of "forest cover type," referring to the composition of the forest canopy. To avoid confusion, the term "forest site-type" is often used to signify Waldtyp and will be used here.*

(1960) have claimed that those criticisms are unimportant. Ilvessalo (1954) admitted that mistakes can be made in assigning land to a site-type, but that misassignments are usually of borderline cases into a site-type similar to the correct one. Kujala (1960) pointed out that the advantage of deep-lying nutrient-rich layers are reflected in the ground vegetation through the fertilizing effect of leaf litter.

More to the point are the reactions of those who have tried to apply site-types. Viro (1961), himself a Finn, stated that the use of ground vegetation to evaluate productivity "is almost confined to Finland; elsewhere it has not been found to give a correct picture of site fertility." Another Finn, Högnäs (1966, pp.94-95), stated that dominant height and age are necessary for practical site quality classification on Finland's Ahvenanmaa (Åland) Archipelago. He ascribed this to the influence of parent materials and the maritimity of the climate, some of the former atypical and the latter completely outside the range of Finnish mainland conditions.

Operational systems of site-types have been developed and tried in Sweden (Eneroth 1931, reviewed by Malmström 1949, Malmström 1949, Arnborg 1953). Site index, however, remains the standard means of estimating productivity there (Carbonnier 1954); site-types are used as a frame of reference for silvicultural prescription (Malmström 1949, Tamm 1950, Arnborg 1960). The Swedish conclusion has been that site-types in Sweden include too much growth variability. In explanation it has been suggested that growth is more sensitive than vegetation composition to differences in elevation, slope direction, and past stand treatment (Malmström 1949, p. 116, Arnborg 1960). Sweden generally has considerably greater elevation contrasts than Finland.

In Latvia the site-type concept was used to classify forest land, with very explicit attention being given to soil profile, stand structure, secondary successions, and forest regeneration in delineating vegetation site-types. These thorough ecosystem studies were considered necessary because the Latvian flora is richer and the soils characteristically deeper and more complex than those of Finland. The resulting site-types were the basis of management on 5 million acres of state and private forests in prewar Latvia (Kabzems 1951).

Interest in site-types has been shown by at least two directors of federal forestry research in Canada, J. D. B. Harrison (1955) and D. R. Redmond (1964). Because of Canada's size and climatic diversity, the government has published a complete geographic classification of the country into forest regions and sections. It is based on community-habitat relations, and reflects differences in climate and physiography (Halliday 1937, revised by Rowe 1959). This Canada-wide classification serves as a framework for development of sectional classifications of habitats based either on vegetation or environment. Classifications based on vegetation have been made for several sections (Linteau 1955, Lemieux 1963, Damman 1964, Mueller-Dombois 1964) and for independently delineated but more or less comparable areas (Illingworth and Arlidge 1960, Loucks 1962a, Wilton 1964).

Krajina (1963, 1964, 1965) and his students have made a number of detailed ecological studies apparently aimed at the eventual classification of the ecosystems of British Columbia according to the vegetation.

Habitat has been classified according to vegetation in several parts of the United States (Heimburger 1934, Kittredge 1938, Westveld 1951, Daubenmire 1952, 1961, Becking 1954, cited in Becking 1957, Heinselman 1963). In general, however, interest has not been strong. Coile's (1938) critical views discussed earlier seem to express the skepticism of United States foresters, who have preferred other approaches; most United States ecologists outside of forestry have been occupied with other problems.

Ordination

Gleason (1926, 1939) questioned the reality of plant "associations," and viewed the composition of vegetation as a response to variations in environment and history. The environment, in turn, can be regarded as a continuum, as reflected in the established climatological practice of mapping isotherms, isohyets, and so forth, and in the well-established concept of the soil catena (Bushnell 1942). Curtis and his collaborators (Curtis and McIntosh 1951, Brown and Curtis 1952, Bray and Curtis 1957, Maycock and Curtis 1960, McIntosh 1967, and others) showed that vegetation also is a continuum, although the segments of that continuum are geographically disjunct. They ordered local and regional communities against one or more

phytosociological axes to investigate successional and other community dynamics.

Goodall (1953a, 1953b, 1954) proposed the term "ordination" for the arrangement of vegetational data along axes.

Wiedemann (1929, cited by Bakuzis 1962) arranged the Finnish site-types against theoretical gradients of moisture and nutrients. Eneroth (1931, reviewed by Malmström 1949) and Arnborg (1953) have done the same thing with Swedish site-types (fig. 2).

Westveld and Spurr (Spurr 1952, p. 305) developed a "provisional indicator spectrum" for the northeastern United States, in which the plant species are ordered against a single gradient that ranges from dry-infertile to moist-fertile. A plot value on the scale is the result of the combined species presences. The reality of a single gradient that combines moisture and "fertility" is questionable, but Spurr's purpose was simply to illustrate a concept, and not to provide a working system.

Rowe (1956) discussed considerations in the use of plants as indexes to environmental gradients, and developed a trial "vegetation moisture index" for the Mixedwood Section of Manitoba and Saskatchewan based on the species present and their apparent affinity for moisture. The rank of vegetation moisture indexes on his plots was generally similar to the soil moisture regime of the plants involved, with ranking based on soil and topography.

NUTRIENT SUPPLY

DEGREE OF MOISTNESS	Poor (Dwarf-shrub series)	Good (Lastrea-dwarf-shrub series)	Rich (Forb-dwarf-shrub series)	Abundant (Forb series)
Very dry	*Very dry dwarf-shrub type*			
Dry	*Dry dwarf-shrub type*	*Dry Lastrea-dwarf-shrub type*	*Dry forb-dwarf-shrub type*	
Fresh	*Fresh dwarf-shrub type*	*Fresh Lastrea-dwarf-shrub type*	*Fresh forb-dwarf-shrub type*	*Fresh forb type*
Moist	*Moist dwarf-shrub type*	*Moist Lastrea-dwarf-shrub type*	*Moist forb-dwarf-shrub type*	*Moist forb type*
Wet	*Wet dwarf-shrub type*	*Wet horsetail-dwarf-shrub type*	*Wet forb-sedge type*	*Wet forb type*

Figure 2.--Forest types of northern Sweden, arranged against theoretical ordinates of moisture and nutrients (Arnborg 1953). Each type is defined by its vegetation. In this early case, ordination was simply an aid in classification.

He concluded that plants can provide useful indexes to environmental gradients if the regional ecology of the species is known well enough.

Hodgkins (1960) tested a vegetation index to loblolly pine site quality for a small area on the Alabama Coastal Plain. He assigned an index value to each of a number of plant species, based on the average loblolly pine site index of the plots on which the species was found, and adjusted the values according to the apparent affinity of the species for soil moisture. The value of a species on a plot was weighted according to its abundance on the plot. The plot means of weighted species values, used in a regression equation, predicted loblolly pine site index with a standard error of only ±2.55 feet.

Of operational interest is the fact that almost all the species used by Hodgkins can be identified year round.

Bakuzis (1959) developed an operational system of vegetation indexes to forest environments in Minnesota, which he called "synecological coordinates." Bakuzis and Hansen (1959) compiled a list of the forest plants of Minnesota, and assigned each species a value for heat, nutrients, and light. Maximum values were 5; minimum, 1. The first approximation values were based mainly on the geographic distribution and the known ecology of the species. For example, a species having its northernmost occurrence on exposed south slopes in southern Minnesota would be assumed to have a high heat requirement for that State and would be given a maximum heat index value. Values for each species then were adjusted if the values of its associates indicated adjustment was appropriate.

The moisture value given to any plot was the average of the moisture values of the species found on it. Heat, nutrient, and light values were figured in the same way.

In developing similar vegetation indexes for the Coastal Redwood Region, Waring and Major (1964) measured available moisture, available nutrients, and solar radiation on plots to assign species values. Correlation between the vegetation moisture indexes of plots and their measured minimum available moisture was particularly strong (r = 0.97). Pluth and Arneman (1965) found Bakuzis' moisture and nutrient ordinates strongly correlated with such soil factors as moisture-holding capacity, silt-plus-clay fraction, and exchangeable potassium.

Site index (fig. 3) and basal area have been related to synecological coordinates (Bakuzis et al.

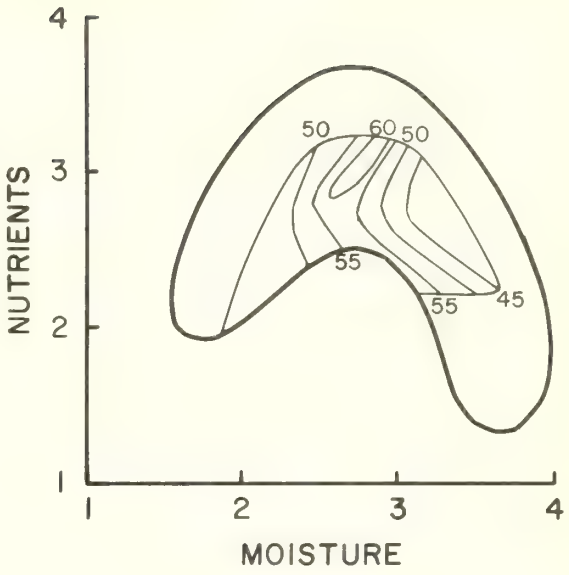

Figure 3.--Balsam fir site index distribution against phytosociological moisture and nutrient ordinates in the Central Pine Section of Minnesota (adapted from Bakuzis et al. 1962). The heavy outline encloses the set of all forest environments in the section. The lighter outline encloses the set of all forest environments on which balsam fir site indexes were determined.

1962, Waring and Major 1964) as has the abundance of tree reproduction (Bakuzis 1959, Bakuzis and Hansen 1962a). In the Border Lakes District and the Central Pine Section of Minnesota, the moisture and nutrient ordinates combined accounted for 36 percent of the variation in jack pine site index (Frissell and Hansen 1963). Synecological coordinates have also been used in the examination of various other ecological relationships (Bakuzis 1962 et seq., Waring and Major 1964).

On the basis of the limited published work on vegetation ordination, it appears that systems developed specifically for estimating site index may provide quite accurate estimates, while more general systems that can be used for a variety of purposes may not estimate site index very well.

The presence and abundance of each plant species expresses a set of environmental factors more or less unique to that species. A community of plants should express pretty much all of the biologically relevant factors and interactions. Vegetation ordination uses communities to express that

integration of factors more flexibly than classification does. The ways in which plant communities integrate factors are hidden, however, and are relatively unamenable to analysis. It is likely that improved vegetation ordinations will come mainly from aiming ordination at narrowly defined purposes, as Hodgkins did, and from improved index values based on instrumented field studies of species (Cleary and Waring 1969).

Environmental Approaches

Environmental approaches to habitat evaluation or description are treated here as either factorial or holistic. The factorial approach uses one or more environmental factors believed limiting to the biological process of interest. The holistic approaches subdivide or ordinate the environment as a whole.

Factorial Approach

In the section on site index it was pointed out that many locations do not have stands suitable for the direct determination of site index. A natural reaction has been to look for a simple method of approximating site index by relating it to one or more limiting factors. This is the factorial approach, which has been restricted largely to the United States.

Haig (1929), in a pioneering study, used the silt-plus-clay content of the soil to estimate site index for planted red pine on brown forest soils in Connecticut. The approach received increasing attention under the leadership of T. S. Coile at Duke University, beginning with his paper "Relation of Site Index For Shortleaf Pine to Certain Physical Properties of the Soil" (Coile 1935). Scores of studies have since been made for different species and areas; an extensive review was written by Della-Bianca and Olson (1961).

The usual technique can be divided into the following steps:

1. Selection of the environmental factors which might limit or be otherwise related to site index.
2. Selection from among them of factors deemed practical to work with.
3. Definition of a study universe which will restrict as many of the other factors as feasible to a reasonable degree of uniformity. (The importance of this step was not fully appreciated during the early development of the method.)
4. Location of plots in stands suitable for site index determination on habitats sampling the range of variability of the factors being studied.
5. Collection of site index and environmental data.
6. Stepwise regression analysis. The equation to be accepted will include those independent variables that are statistically significant and that also contribute appreciably to the accuracy of the site index estimates.

An alternative to regression analysis is the progressive subdivision of pertinent factor gradients (Gysel and Arend 1953, Strothmann 1960).

Early habitat studies were made in areas of subdued terrain. Climatic variability was restricted by limiting the area included in the study. The Southeastern Section of the Society of American Foresters recently provided a geographic division of a three-State region—Alabama, Florida, and Georgia—into seven provinces and 20 habitat regions based on physiography (Hodgkins 1965). Superimposing a climatic classification, it felt, would provide an excellent framework for studies relating site index to soil and topography.

Different studies have shown different factors to be significant, depending on the species, the factors examined, their intensity range, the manner in which they were measured and expressed, and the statistical and biological relations between the "independent" factors. Nash (1963) points out that "for an independent variable to show partial correlation at a significant level, it must be a variable not a relatively static quantity." He might have added that it must also not be strongly correlated with another independent variable which varies even more harmoniously with site index.

In most studies, soil factors or topographic factors that influence or reflect moisture supply have been important. Examples are studies by Haig (1929), Coile (1935), Gysel and Arend (1953), Young (1954), Weitzman and Trimble (1955), Trimble and Weitzman (1956), Zahner, (1957), Stoeckeler (1960), Cooley (1962), Hebb (1962), Smalley (1964), Carmean (1965), and Kormanik (1966), and in the western United States Carmean (1954), Copeland (1958), Zinke (1959), Myers and Van Deusen (1960), Choate (1961), and Steinbrenner (1965). The factors included soil depth, stone content, soil texture, imbibitional water value of the subsoil, depth to mottling, degree of slope, slope position, aspect, and the concavity or convexity of the slope.

Even without chemical soil analysis, the apparent nutrient regime often seems important. Studying ponderosa pine in the Black Hills, Myers and Van Deusen (1960) found soils derived from limestone to differ in site index from soils derived from crys talline rocks. Yawney (1964) found oak site index in West Virginia to be higher on soils from limestone that on soils from shale and sandstone. Minnesota aspen grew faster on calcareous than on noncalcareous drift (Stoeckeler 1960). In Ontario, Chrosciewicz (1963) found higher jack pine site indexes on glacial drift with a higher proportion of basic minerals, and Heinselman (1963) related forest growth to the mineral status of bog water in northern Minnesota peatlands.

The importance of climate other than microclimate is apparent from several studies. Zinke (1959) found the site index of Douglas-fir and ponderosa pine related to average annual precipitation in northwestern California. Stephens (1965) found that Douglas-fir site index in the Cascade Range in northwestern Oregon varied substantially between different great soil groups, an effect which he said "appears to be associated with climate." Stoeckeler (1960) stated that aspen in the Turtle Mountains of North Dakota grow more slowly than in northern Minnesota because of substantially less precipitation. When Hill et al. (1948) compared similar soils in adjacent counties of Washington, they found that although both received abundant precipitation, the sites with somewhat greater rainfall had a Douglas-fir site index about 30 feet higher than those in the other area. Carmean (1954) also found that Douglas-fir site index increased with precipitation in southwestern Washington. Choate (1961), Hayes and Hallin (1962), and Steinbrenner (1965) all found elevation influential, presumably through its influence on temperature, precipitation, or both. Jack pine site index in Ontario differs from one climatic section to another (Chrosciewicz 1963). Latitude was significantly correlated with the site index of shortleaf pine (Coile and Schumacher 1953) and that of Douglas-fir (Choate 1961), presumably due to changes in temperature and possibly in precipitation.

The suitability of a site index estimating equation usually is evaluated by examining the coefficient of determination or the standard error. These express the overall accuracy of the estimates more or less correctly, depending on how well the distribution of the variables meets certain prerequisites (Ezekiel 1941, p. 16.). Covell and McClurkin (1967) observed that equations for estimating site index from habitat variables seldom account for more than 50 to 60 percent of the site index variance. Their own equation, for loblolly pine on a single soil series, accounted for 63 percent of the site index variance although a wide longitudinal range was included (Alabama to Texas). Myers and Van Deusen (1960) related ponderosa pine site index to habitat factors, for the limestone area and separately for the area of metamorphic rocks, in the Black Hills. Each of their equations accounted for 80 percent of the site index variation. Carmean (1965), working with black oak in southeastern Ohio, developed a different equation for each of two soil textural groups. Like a number of workers, he used a transformation of height as the dependent variable and age as an independent variable. Each of his equations accounted for 80 percent of the variance in tree height, probably due to narrowly and appropriately defined study universes. That is not as good as accounting for 80 percent of the site index, however. . The variance in height was considerably greater than the site index variance would have been, and a large part of it is accounted for by age.

Areas such as the Rocky Mountains of Colorado comprise a complex of environmental variables, many of which have a wide range of variability even within a single cover type. These variables may limit biological behavior in a variety of combinations; many interact ecologically and are confounded statistically. In such an area, the factorial approach by itself seems unlikely to provide a useful estimator of productivity. It has proved useful, however, when used within narrow subdivisions of a regional environment—for example, the two primary geological subdivisions of the Black Hills (Myers and Van Deusen 1960). To divide the Colorado Rockies into units of comparable climatic-geologic homogeneity might require a more formal classification incorporating several criteria—a holistic classification as a framework for the factorial approach.

Holistic Approaches

In one holistic approach, the environment is classified by classifying the landscape as a whole. That is the basis of the soil survey approach and German site mapping. It is also the working basis of the physiographic site classification of G. A. Hills (1952 et seq.).

Another holistic approach is to develop a theoretical though more or less arbitrary model of the environment, measure or estimate the necessary environmental variables, and incorporate them in the model. This is the conceptual basis of Hills' physiographic site classification. Loucks (1962b) and Jones (1967b) carried it further in ordinating forest environments in New Brunswick and in the Southern Rocky Mountains, respectively.

Holistic approaches will be discussed as (1) soil survey, (2) German forest soil maps, (3) Hills' physiographic site types, and (4) environmental ordination.

Soil Survey.[5] —Retzer (1958) criticized the factorial approach as providing only a productivity appraisal. Other purposes would require remapping the management area on other bases. He felt that mapping soil taxonomic units provides a sound general basis for wild land management including productivity appraisal.

A soil is not simply a soil profile with certain characteristics. It is a three-dimensional segment of the landscape with a characteristic profile and shape. Soil surveys divide the landscape into taxonomic units. Available forest soil survey maps are based either on the recent 7th Approximation classification (Soil Survey Staff 1960) or on the preceding classification (Soil Survey Staff 1951). In either case, the basic mapping taxon is the **soil series.** The differences between series are narrow. Series including more than one surface soil textural class may be subdivided into types according to texture. Phases may also be recognized, based on soil depth, stoniness, slope, and the like (Soil Survey Staff 1951). Series are defined and recognized by characteristics of the soil profile that reflect the climate, organisms, topography, parent material, and time (Jenny 1941). Some of the classifying criteria have direct significance to plants, and soil phases are delineated by characteristics important to ecology and land management.

The utility of soil maps in ecology or wild land management depends on whether the units defined are sufficiently uniform ecologically. This in turn depends on the degree of coincidence of the classification criteria with the characteristics of greatest relevance to problems of forest management. Coile (1960), a man of wide experience in relating southeastern soils to forest growth, felt that the coincidence is inadequate, at least for evaluating yield capacity.

The evidence is not conclusive. In most papers only the soil series is given and phases are not differentiated.

Zinke (1961) found ponderosa pine site indexes (index age 300) ranging from 107 to 180 feet on the Underwood series in California; average annual precipitation ranged from 15 to 35 inches. Site indexes on the Shaver series varied from 89 to 182 feet, with average annual precipitation of 12 to 55 inches! Covell and McClurkin (1967) found loblolly pine site indexes ranging from 59 to 105 feet on 89 plots on the Ruston series.

Stoeckeler (1960) found that soil **types** estimated aspen site index fairly closely on his plots in northern Minnesota and northern Wisconsin. The summer climates sampled were not very heterogeneous, however, and he purposely did not sample rough topography or habitats, the site index of which might be influenced by slope or aspect.

Phillips and Markley (1963) presented site indexes (index age 50) for New Jersey sweetgum by soil series. Eight series were represented by at least three plots each. They had the following site index ranges and sample sizes:

Series	Plots (Number)	SI range (Feet)
Othello	3	2
Matlock	3	4
Bayboro	5	9
Adelphia	5	9
Rancocas	5	12
Weeksville	3	15
Bustleton	5	21
Keansburg	10	23

The authors (pp. 14-16) imply that recognition of drainage phases and water table phases in some series would have improved estimates appreciably.

[5] *In this paper, "soil survey" refers to the classification and mapping of landscapes by the Soil Survey Staff of the U. S. Department of Agriculture and by other public and private agencies using their classification and methods.*

It seems clear that series alone are too heterogeneous ecologically to serve as a basis for evaluating timber productivity, and probably would prove too heterogeneous for other purposes too. Cox et al. (1960) showed the improvement that might be expected in the Rocky Mountains when appropriate phases are recognized.

On the Pacific Coast, series and phases of wild land soils have been mapped (U. S. Forest Service 1954). Types have also been differentiated on some maps (Gehrke and Steinbrenner 1965), presumably when series have considerable textural diversity. Phases are defined not only by ecologically relevant characters of soil and topography, but for some series even by the amount of precipitation (Sauerwein 1965). Three agencies survey wild land soils in California. The U. S. Soil Conservation Service maps soils, while the California Cooperative Soil-Vegetation Survey maps soils and vegetation together, as does the California Region of the U. S. Forest Service (Zinke and Colwell 1965). Vegetation mapping provides a vegetation inventory as well as a classification refinement.

By 1963 over 30 million acres of wild land soils had been mapped in California (Bradshaw 1965). Other large areas, including industrial forests, have been mapped in Oregon (Corliss and Dyrness 1965, Gehrke and Steinbrenner 1965, Sauerwein 1965, Stephens 1965).

The writer has seen no data other than site indexes by which the units delineated by soil-vegetation surveys can be evaluated as ecologically homogeneous units. It seems certain, however, that all the pieces of land on "Q" National Forest designated soil series X phase ab and bearing vegetation type $\frac{OY\ 321}{CHy}$ will be rather similar habitats.

One drawback to soil survey as a habitat classification in forestry is the large and cumbersome number of mapping units—normally series and phases. On 50,000 acres in the foothills and west slope of the Oregon Cascades, 50 different mapping units were recognized (Sauerwein 1965), and on 128,000 acres in the Georgia Piedmont, 73 mapping units were recognized (Byrd et al. 1965).

On the other hand, that multiplicity gives the system versatility. Soil survey classification is not really an ecological classification, but only a basis for one. After the landscape has been classified and mapped, the mapping units must be interpreted for silvicultural or other purposes (Wertz 1966). For example, interpretation data may indicate that the 61 soil mapping units of an area can be grouped into seven sets for the rough classification of timber productivity, and differently into six other sets for prescribing reforestation methods. It then becomes possible to make simpler special-purpose maps from the detailed general map of soil series and phases.

The uses of the soil survey classification of wild lands include not only productivity evaluation, but evaluation of erosion and sedimentation hazards, trafficability, forest regeneration problems, and forest disease and insect problems (Bradshaw 1965, Corliss and Dyrness 1965, Orr 1965, Richlen et al. 1965, Sauerwein 1965).

One might question the use of a primarily pedological classification for wild land management. The classification is based mainly on characteristics that reflect profile development, and are related to forest ecology only indirectly and loosely. The opportunity to include features with specific silvical importance comes only in the recognition of soil phases. Making the maps as useful as they could be by recognizing all the appropriate phases is likely to result in maps that are needlessly hard to interpret. For forestry purposes, pedological mapping might better end with great soil groups or subgroups, which could be subdivided into ecologically defined phases. Much more ecological information could be included in a given number of mapping units.

German forest soil maps.—Wittich (1962) described in English the classification and mapping of German landscapes for forestry purposes. A separate classification is made for each "growth district." The first level of classification recognizes genetic soil groups equivalent to "great soil groups" or "little soil groups" in America, and much broader than our soil series. Further classification reflects solely the effects of the soil, parent material, and topography on the forest; the criteria are ecological rather than primarily pedological. The classification is based on examination and interpretation of many soil pits and the associated vegetation and timber. The soil mapping types or "site-units" (Standorts-Einheiten), though defined by soil characteristics, are as uniform as feasible in ground vegetation and timber productivity.

After the classification is complete, topography, vegetation, and stand characteristics are used as guides so far as possible in mapping the district soils, somewhat as in American soil survey. Because the German mapping types are largely eco-

logically defined, however, they probably are more closely related to vegetation and stand characteristics than are American soil phases. This should make them silvically more homogeneous as well as easier to map.

Hills' physiographic site-types.—G. A. Hills of Canada developed a "total site" classification. He defined total site as "an integrated complex of climate, relief, geologic materials, soil profile, ground water and communities of plants, animals and man" (Hills 1955, p. 120). Actually it is a classification of the physical environment, and the basic units are physiographic site-types. The vegetation helps to set the physical definitions of the physiographic site-types, however, and aids in field identification (Hills 1955, p. 5), as in the German system. After the sites have been classified, the plant communities on each physiographic site-type are described and their successional dynamics are discussed.

Hills presented his concept and methods in essentially their fully developed form for the first time in 1952, and discussed them further in subsequent papers (Hills 1953, 1955, 1960, 1961a, 1962, Hills and Pierpoint 1960). He recognized the environment as a complex whole, and as a working basis recognized three environmental regimes: climate, moisture, and nutrients. Each is treated separately from the others, but the same environmental elements might be considered in more than one regime. For example, soil colloids are significant to both moisture and nutrient regimes, and topography to both climate and moisture regimes.

Macroclimate is held essentially constant by working within geographic sections, either those of Rowe (1959) or, in Ontario, Hills' own. Within a region, microclimates are classified into 10 levels from warmest to coldest. Assignment to a microclimatic rank is based on topographic situation, air drainage, and presence of a water table at or near the surface.

The other regimes are also subdivided into 10 intensity classes. Assignment to a moisture rank is based on the "pore pattern" of the soil—a function of texture and structure—and on soil depth, topographic situation, and water table. Nutrient rank is based on pore pattern, parent material, and profile development.

In a sense this is an ordination system in which units are assigned ordinates on other than quantitative bases.

As in soil survey and vegetation classification, in Hills' system a habitat is assigned to a classification unit according to the practitioner's judgment. Hills' concept, charts, and tables provide a controlling frame of reference and evaluation aids. Hodgkins (1960), after reading a regional physiographic site-type classification (Bedell and MacLean 1952), concluded that it would be difficult for a mapper to identify all of Hills' site-types with precision because of vagueness and overlapping in some of the site-type descriptions. Rowe (1962), a Canadian himself, wrote:

> The close integration and mutual dependence of all elements at all levels in the classification makes Hills' system difficult to comprehend and to apply by any except those who have worked in close association with him.

Both physiographic site-type classification and soil survey classify the landscape directly, but Rowe (1962) pointed out an important difference. In soil survey the soil profile type is of key importance. In contrast, different profile types occur within the same physiographic site-type. Hills considers profile only within the framework of a land-form classification, and then only so far as it seems relevant to forest dynamics.

Compared to soil survey, physiographic site-type classification of an area results in far fewer, and therefore more inclusive, mapping units. Nonetheless, the units may well be as homogeneous ecologically as those of soil survey because they are delineated entirely by factors that seem ecologically important. Bedell and MacLean (1952) classified approximately 8 million acres (as judged from the map) of a topographically diverse forest section north of Lake Superior. They defined only 16 physiographic site-types. In the larger Clay Belt Section of eastern Canada they differentiated 17 site-types (MacLean and Bedell 1955), while in a 50-million-acre section of northern Alberta, Duffy (1965) defined 12 site-types.

Perhaps this relative simplicity would be less in the mountainous West. A system similar to Hills' was used by Lacate (1965) to classify and map mountain habitats in British Columbia. On 9,800 acres of rugged land with a complex of soil parent materials—tills, colluvium, alluvium, outwash, and lacustrine deposits—he classified and mapped 40 physiographic site-types. Whether that larger

number is entirely the result of greater environmental complexity or to some extent of finer splitting cannot be evaluated from a distance.

Farrar (1962) felt that, for use in the mountainous West, physiographic site classification should consider precipitation in the moisture regime.

Physiographic site-type classification serves several purposes. The units are intended to be approximately homogeneous in timber productivity and successional dynamics, and consequently a good basis for productivity evaluation and silvicultural prescription. Pierpoint (1962) provided an example of the classification of a large area, with complete mapping of site-types and detailed description of vegetation and succession. Physiographic site-types also have served as the basis for land use capability ratings which consider the potential for agriculture, wildlife, and recreation as well as for timber production (Hills 1961b).

For interregional comparisons, Hills' system includes universal as well as regional scales. As it apparently provides no effective way of assigning macroclimatic values, the meaning of such comparisons seems limited.

Environmental ordination.—In ordinating environments, one or more environmental gradients are defined. Each ordinate integrates relevant habitat factors by means of a theoretical model and the available data. For example, Thornthwaite and Mather's (1955) annual "soil moisture deficit" is a moisture regime ordinate that integrates experimental data on precipitation, evapotranspiration stress, soil moisture storage capacity. and so forth.

In the Green River drainage of New Brunswick, Loucks (1962b) applied scaling to Hills' environmental regimes. Whereas Hill integrated factors subjectively, using insight and trained judgment, Loucks integrated them using theoretical but defined relationships of factors to one another and to plants. He related the composition and structure of forest communities to the resulting environmental ordinates, or "scalars."

The way in which Loucks constructed his "synthetic moisture regime scalar" illustrates his methods in general. This scalar, which he terms "a first approximation," includes only landscape factors. Precipitation is assumed to be essentially uniform within the area studied, and evapotranspiration is dealt with separately and indirectly outside the moisture regime scalar. The moisture regime scalar is a synthesis of two subordinate scalars. One combines the water-holding capacity of the soil and depth to water table. The other, called the runoff scalar, combines degree of slope and topographic position.

In the Green River drainage, Loucks found that...

> on soils where the prevailing water table occurs within 7 ft of the surface...little or no relationship exists between water-holding capacity and forest composition. This is to be expected, in view of the high precipitation and sustained supply of ground water.

Consequently, water-holding capacity was integrated into the moisture regime scalar only for habitats with the water table below 7 feet. Furthermore,...

> a difference of 1 ft in the depth to the water table in shallow soils results in considerably more change in the vegetation than a difference of 1 ft where the water table is deeper. The gradient is therefore considered to be logarithmic. The range in depth to the water table from zero to several feet can be expressed as a scalar beginning with zero, by adding unity to the observed depth, and using the base-10 logarithm of the sum.

Quoting Loucks again, but deleting citations, the runoff scalar was based on these considerations:

> Two separate [literature] sources indicate that average [storm] run-off, in percent, rises sharply with initial increase in slope to about 18% on a slope of 10%. Thereafter, increase in run-off is more gradual. Average run-off values...at regular intervals of percent slope may then be used to calculate the retention of heavy rains plotted in [Figure 4]. The average fall of rain has been expressed as unity. On a horizontal surface all of it is retained. On a 20% slope 21% is lost in run-off, and assuming little or no replacement at the slope-crest position, 0.79 of the rainfall is retained. Farther downslope, the 21% run-off is added to the unit rainfall; a 21% loss of this total leaves a retention of 0.96. Slopes of 5% gradually come to equilibrium, loss equalling gain. At the foot of the slope, however, an average net run-off of 1% results in an accumulation, the amount depending on the antecedent slopes.

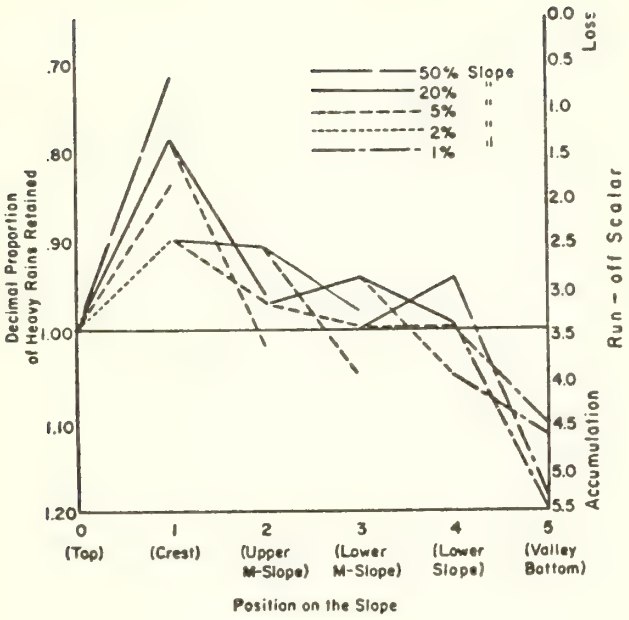

Figure 4.--Nomogram for a runoff scalar based on slope steepness and position (Loucks 1962b). (Reprinted with permission from Professor Loucks and from Duke University Press.)

The synthetic moisture regime scalar was then constructed as follows:

> Field observations indicate that on well-drained soils the effects of run-off are only half as important as water-holding capacity. Thus, [in Figure 5,] the slope of synthetic scalar units of equivalent magnitude was established as $y = 2x$ in the area where run-off effects are near neutral and the water table is beyond 7 ft. Because run-off as a moisture factor is negligible where the water table is at or near the soil surface, the slope of the relationship changes gradually from deep to high water tables. Therefore, the original $y = 2x$ slope was extended beyond the upper margin to intersect with the right hand margin of the nomogram, the zero depth to water table. The angle subtended at this intersection by the entire range in run-off and depth to prevailing water table was divided equally into the 10 units of the synthetic Moisture Regime scalar. Thus, proportionately less emphasis is given the run-off component under conditions of a high water table.

Figure 5.--Nomogram for a synthetic moisture regime scalar. Positions of samples used in the study are indicated by the dots (Loucks 1962b). (Reprinted with permission from Professor Loucks and from Duke University Press.)

The more complex synthetic nutrient regime scalar integrates silt-plus-clay content of the soil, depth of solum, A_1 horizon minus A_2 horizon, the degree of organic decomposition, and the runoff scalar already mentioned. Parent material was essentially uniform throughout the study area, so it was not included.

The synthetic local climate regime scalar is a synthesis of slope and aspect as they affect daytime temperatures, elevation and topographic position as they influence nighttime temperatures, and the thermal effect of soil moisture as expressed by the moisture regime scalar.

Of necessity, Loucks' pioneer scalars include abundant assumptions and relatively modest supporting data. With them he illustrated a new approach to habitat evaluation, and worked out basic methods. The natural distribution of forest species within the resulting continuum model suggests that even this first model is a reasonable approximation of nature. He did not try to relate site index to it.

Jones (1967b) was assigned the development of an equation for estimating aspen site index in Colorado and northern New Mexico from habitat factors. Aspen forest in that region occurs from about 8,000 feet elevation to nearly 11,000 feet, in climatic areas with moisture deficits varying from brief and mild to long. The length and warmth of growing seasons differ substantially. Stands occur on level tablelands and on moderate and steep mountain slopes of every aspect, and on shallow stony soils as well as deep heavy soils. Soils are derived from a wide variety of parent materials. He concluded that the factorial approach was not suited to more than local equations in a region where so many variables might be limiting and in such a variety of combinations. For this reason he turned to ordination.

Moisture regime and temperature regime ordinates were developed. Because of moderate or high site indexes on several plots very low in nutrients, it was concluded that a nutrient regime ordinate was not needed.

The temperature regime ordinate was defined as the total number of degrees by which the average daily maximum temperatures for the months exceeded a threshold temperature. It integrates the length and warmth of the growing season and is analogous to degree-days. The temperature regime ordinates of plots were estimated by a regression equation for the appropriate subregion, with elevation and latitude used as independent variables.

A number of factors were incorporated in the moisture regime ordinate. Multiple regressions were developed from published precipitation records and variables from topographic maps to estimate the normal precipitation of any month for any plot in the region. Other equations were developed to estimate average monthly temperatures, which in turn were adjusted according to the theoretical monthly direct beam insolation as determined by slope and aspect. Thornthwaite and Mather's (1957) tables for estimating soil moisture deficits were used to integrate the effects of estimated normal monthly precipitation, adjusted mean monthly temperatures, and the water-holding capacity of the soil. The latter incorporates soil depth, percentage of the profile occupied by stone, and soil texture. The procedures deviate from those of Thornthwaite and Mather, and the habitats involved fall outside the universe which their tables properly represent. The resulting plot value was therefore regarded as an abstract climate-soil moisture index rather than as an estimate of the soil moisture deficit in inches.

A runoff index was developed to express the effects of runoff inflow and outflow on soil moisture. It incorporated seasonal moisture surplus, the concavity, straightness or convexity of the topographic profile and contour, and the presence or absence of an accessible water table.

The climate-soil moisture index and the runoff index were then combined into a single moisture regime ordinate.

Plots were established to sample the environmental range of aspen stands in the region. The temperature regime and moisture regime ordinates were calculated for each plot, and the multiple regression of site index on the two environmental ordinates was computed. Both partial regression slopes were statistically significant and, combined, accounted for a little more than 30 percent of the total site index variation.

Various assumptions made in constructing the ordinates probably caused much of the unaccounted-for variation in site index. A consideration of aspen genetics, ecology, and sexual and asexual reproduction suggested that another substantial part of the site index variability probably resulted from genetic variability between clones in the Southern Rocky Mountains. Clonal genetic variability was very largely interplot variability, and its effects were therefore confounded with habitat effects. This problem in evaluating aspen sites was discussed by Zahner and Crawford (1965).

As with vegetation ordination, environmental ordination can be either broad and unspecialized, like that of Loucks, or aimed at a specific and narrow purpose, as Jones'. Environmental ordination differs from vegetation ordination in two important ways, however:

1. An environmental ordination reflects how we believe the environmental factors act together to influence plants. Therefore, the success of that ordination is limited by how correct our understanding is.
2. As we improve our understanding of how environmental factors interact to influence plants, we can provide improved environmental ordinations.

So far, environmental ordination is in a primitive stage of development. Theoretically it has much to recommend it, but its actual worth has not yet been demonstrated.

Summary and Conclusions

Rowe (1962) points out that "purpose is implicit in all classifications and different purposes lead to different classifications." The different backgrounds of different classifiers, and the different climates, terrain, and vegetation of the regions where they work also lead to different classifications. Cajander's (1909, 1926) system of forest site-types resulted from a botanist looking at relatively simple ecosystems in a country with a subdued terrain, a subcontinental boreal climate, and a flora of unusual paucity. Coile's (1938) criticisms of it grew from his experience as a soils scientist in a region of deep soils, very rich flora, and much more diverse secondary succession.

Every approach discussed here seems valid and valuable for some purposes and in some conditions.

So far as forestry is concerned, the primary purposes of site classification or ordination are (1) to identify productivity, and (2) to provide a frame of reference for silvicultural diagnosis and prescription. In the United States to date, most attention has been given to the first purpose—identification of productivity. We have given very little attention specifically to classification or ordination for the second purpose. Systems that might be well suited to the second purpose have been recommended for the identification of productivity instead, and criticized as unsuited to it.

Where it can be used, site index identifies productivity most directly and perhaps best. It is also very useful in the development or application of supplementary and alternative approaches.

The factorial approach can identify productivity satisfactorily when site index cannot be used, providing the equation or table is developed and used in a universe where the limiting variables are neither too numerous nor their relationships too complex. In some physiographic provinces, a factorial site index equation may apply to a rather extensive area. It probably would be necessary to subdivide some other provinces into a number of subprovinces defined by climate, geology, physiography, or some other characteristics, developing a different equation for each.

Vegetation classification, soil (actually landscape) classification, and classification of physiographic site-types have the advantage of being readily used for mapping. For forest management purposes, maps of vegetation types or landscape units have great potential value. Results of silvicultural, pathological, and mensurational research can be referred to the conditions to which they apply, making silvicultural prescriptions, for example, much likelier to succeed. The mapping units by themselves, in some cases, may identify productivity adequately. Where they do not, they would define narrow universes for the simple and accurate use of the factorial approach. Once such maps are available and silvicultural and mensurational research has been correlated with the mapping units, site evaluation and reliable silvicultural prescription often will be primarily a matter of consulting a map, with field checks when desirable.

Detailed soil survey maps—as detailed as those for agricultural land—are becoming available for many areas, particularly in the southeast.[6] In such areas these maps undoubtedly will serve as the primary basis for site evaluation, even though some other approach might have been preferable.

The German approach to landscape mapping seems more appropriate for forestry than does the Soil Survey approach. Where soil survey maps are available, they could make the German approach easier by providing abundant soil information as well as an initial segregation into broad genetic soil groups. The soil-vegetation maps available in some areas would also be useful in the initial correlation of landscape characteristics and vegetation in the German approach.

Hills' approach may also be preferable to that of Soil Survey. It is difficult to compare Hills' approach with that of the Germans. In concept they are very different, but in practice they seem to have much in common. Wittich's (1962) description suggests the Germans subdivide more finely.

Theoretically it should be possible to map synecological or environmental ordinates by entering point values on a map and drawing isolines. Such mapping seems impractical, however, because of gradient discontinuities and reversals. On the other hand, ordination of either vegetation or environment should prove useful in classifying vegetation or landscapes. Ordination can provide a continuum model or coordinate field within which plots can be related to one another by their coordinates (see fig. 3). This can provide a primary basis for deciding what conditions should be included to-

[6] *Letter from Professor Earl J. Hodgkins, Auburn University, Auburn, Alabama to G. Lloyd Hayes, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. June 6, 1968.*

gether in a type for mapping. Vegetation types or landscape units could then be defined initially by the set of ordinates that each includes. More easily recognized criteria would then be developed for field mapping. Determination of ordinates could sometimes help in mapping, particularly in mapping vegetation types under disturbed conditions.

The results of a silvical or silvicultural study are always valid only within certain conditions set by places and times. In appropriately designed field studies, the place (site) can be defined by soil or vegetation mapping units. With environmental coordinates, however, it should become possible to define even artificial environments to some extent, as equivalent to certain field conditions. It should also be possible to state that, because of abnormal weather during a season, the effective environment of a site was approximately normal for coordinate (m, t, n), even though the site is defined as (m', t', n'). Eventually it may become possible to estimate success probabilities for silvicultural treatments at given environmental coordinates.

Environmental coordinates can also provide a basis for the comparison of seed sources in different regions if the coordinate model is valid for both regions.

Factors are integrated into synecological ordinates in an unknown and unadjustable way by the vegetation. On the other hand, satisfactory environmental ordinates depend on our knowledge of ecosystem dynamics. As knowledge increases, environmental ordinate models can be adjusted and refined, which does not seem true of synecological ordinates. Synecological ordinates seem easier to assign in the field, however. Pits need not be dug nor nutrient analyses made.

A case can then be made for a sequence of regional site research (fig. 6).

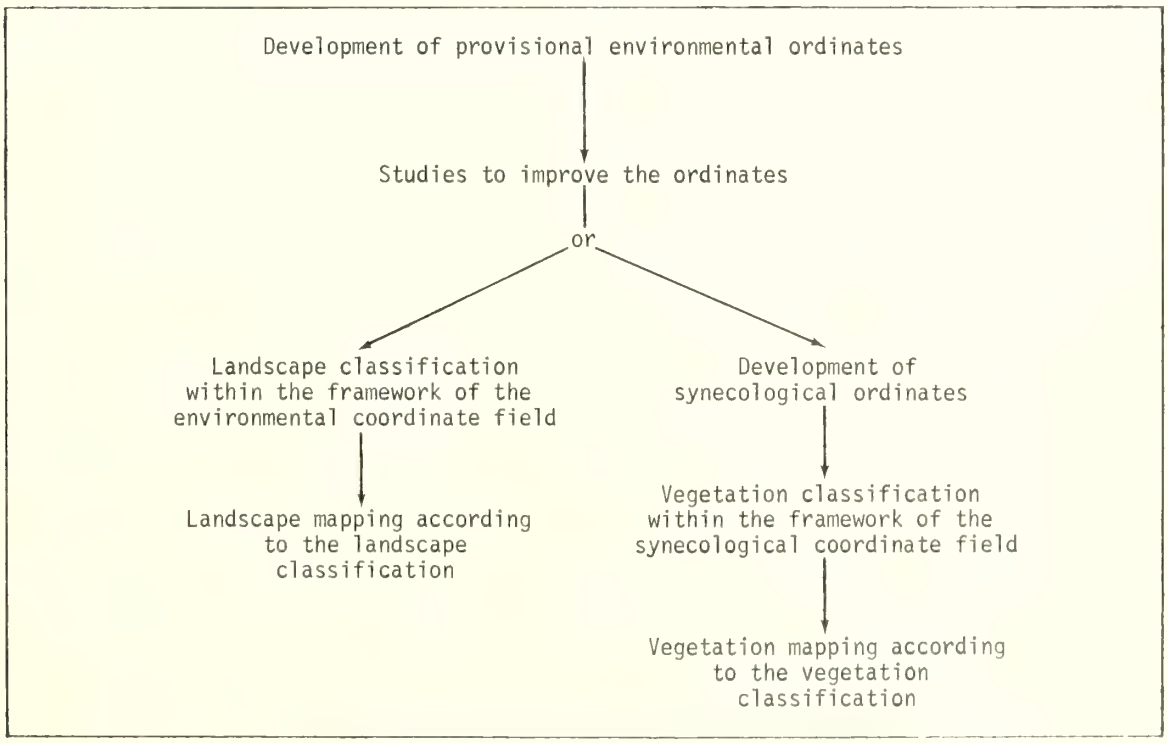
Development of provisional environmental ordinates
Studies to improve the ordinates
or
Landscape classification within the framework of the environmental coordinate field
Landscape mapping according to the landscape classification
Development of synecological ordinates
Vegetation classification within the framework of the synecological coordinate field
Vegetation mapping according to the vegetation classification

Figure 6.--Sequence for regional site research.

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COMMON AND SCIENTIFIC NAMES OF PLANTS, INSECTS, AND DISEASES MENTIONED

Plants

Aspen, bigtooth	*Populus grandidentata* Michx.
Aspen, quaking	*Populus tremuloides* Michx.
Birch	*Betula verrucosa* Ehrh.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Fir, balsam	*Abies balsamea* (L.) Mill.
Fir, subalpine	*Abies lasiocarpa* (Hook.) Nutt.
Oak	*Quercus* spp.
Oak, black	*Quercus velutina* Lam.
Pine, eastern white	*Pinus strobus* L.
Pine, jack	*Pinus banksiana* Lamb.
Pine, loblolly	*Pinus taeda* L.
Pine, lodgepole	*Pinus contorta* Dougl.
Pine, ponderosa	*Pinus ponderosa* Laws.
Pine, red	*Pinus resinosa* Ait.
Pine, Scots	*Pinus sylvestris* L.
Pine, shortleaf	*Pinus echinata* Mill.
Pine, western white	*Pinus monticola* Dougl.
Spruce, Engelmann	*Picea engelmannii* Parry
Sweetgum	*Liquidamber styraciflua* L.

Insects

Budworm, spruce	*Choristoneura fumiferana* (Clem.)

Diseases

Dwarf mistletoe	*Arceuthobium campylopodum* f. *campylopodum* (Engelm.) Gill
White pine blister rust	*Cronartium ribicola* Fischer

Jones, John R.
1969. Review and comparison of site evaluation methods. USDA Forest Service Research Paper RM-51, 27 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

Both the productivity of sites and their characterization for silvicultural purposes are considered. The review covers site index; classification of vegetation site types and physiographic site-types; soil-site equations; classification and mapping of forest soils as done in the United States and Germany; and the ordination of vegetation and of physical environments into gradients representing moisture, temperature, and nutrient regimes. Advantages and limitations of the methods are discussed, and a sequence is suggested for regional site research programs.

Key words: Site index, silviculture, soil mapping, ordination

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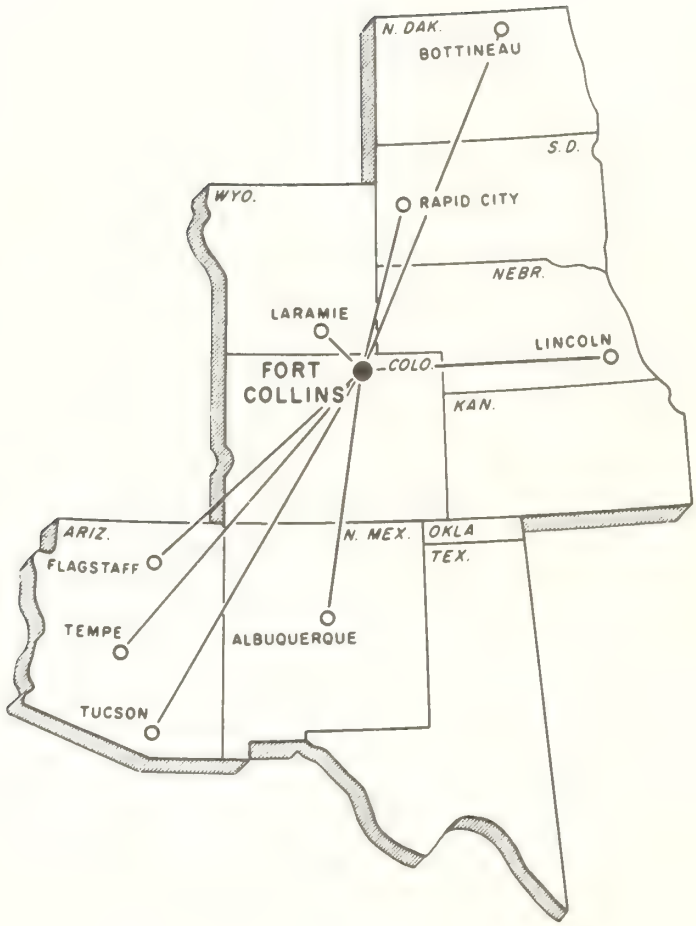
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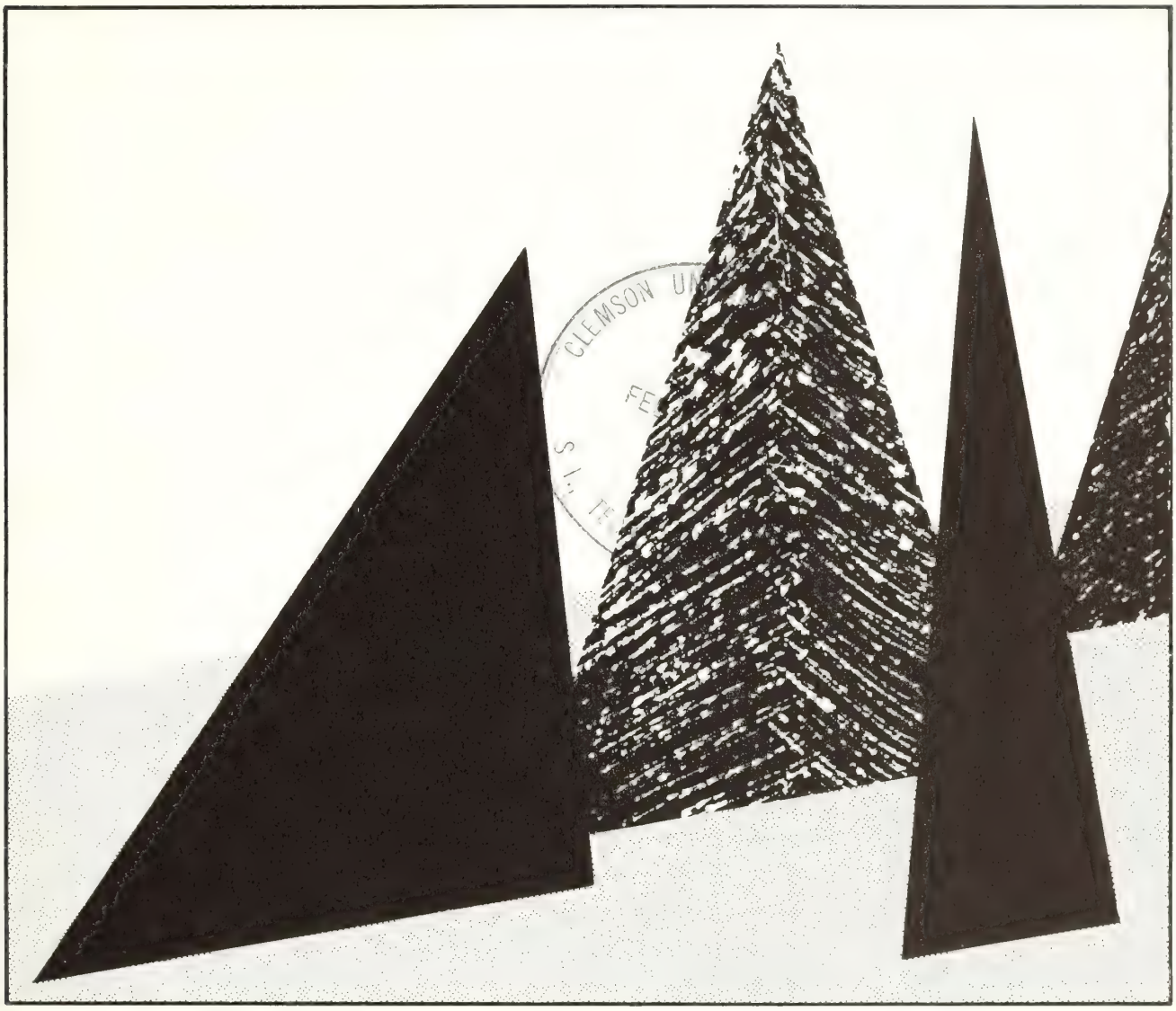
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nocturnal air temperature on a forested mountain slope

by

james d. bergen

Rocky Mountain Forest and Range Experiment Station
Forest Service-U.S.Department of Agriculture Fort Collins, Colorado 80521

USDA Forest Service
Research Paper RM-52

1969

Nocturnal Air Temperature on a Forested Mountain Slope

by

James D. Bergen, Meteorologist

Rocky Mountain Forest and Range Experiment Station[1]

[1]Central headquarters maintained at Fort Collins, in cooperation with Colorado State University.

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Nocturnal Air Temperature on a Forested Mountain Slope

James D. Bergen

In mountainous terrain, the spatial pattern of nighttime temperatures measured in standard screens should largely reflect topography. Unfortunately, towns and permanent weather stations are commonly located in canyons and river valleys, while the ecologist and forest-protection officer are usually concerned with the temperatures found on the forested slopes above such stations; they are also less concerned with the temperature at a standard screen height than with the temperature at some level in the forest canopy or at the surface of the slope.

The common assumption that air temperatures vary with elevation on a slope in the same way that air temperatures vary with altitude in the nearby free atmosphere is plausible only when the net radiation at the slope surface approaches zero. This situation is possible on days or nights with considerable low cloud cover and in early evening for most days, but not on those still, clear nights on which minimum temperatures are likely to occur. For such nights the movement of air and the pattern of surface isotherms follow the details of the topography in a complex way. The cold air layer generated by radiation cooling is shallow, with a depth on the order of tens of meters. Such layers may not extend far above the forest canopy, and small topographic features such as ridges or gullies interact directly with the structure of the canopy to determine the vertical temperature profile at any position along the slope.

The data to be discussed in this Paper were collected during an exploratory study of the joint effect of these factors on the nocturnal temperature of a highly divergent, heavily forested slope typical of much of the Colorado Rockies.

Study Site

A slope of simple geometry was selected for the study; the elevation contours are shown in figure 1. The forest cover is a mixed stand of Engelmann spruce (Picea engelmannii Parry) and subalpine fir (Abies lasiocarpa (Hook.) Nutt.), which attain a maximum height of about 18 meters (m.). The hill rises to a maximum height of about 200 m. above the Fraser River valley near Fraser, Colorado, and faces east with a relatively open horizon.

Measurement stations established on the slope (fig. 1) were chosen to approximate points along a streamline for the cold air movement off the slope; the assumption was that such movement is normal to the elevation contours. When a number of adjacent streamlines are estimated by this assumption (fig. 1A), a feature is emphasized which may be noted only fleetingly from the contour maps, and which would not be apparent from a two-dimensional cross section (fig. 1B). This feature is a center of divergence, or more rigorously, the end of a line of divergence labeled (C). Point (C) may be shown to be a region where the motion of air in response to temperature differences between the air on the slope and that over the valley must be primarily normal to the slope. This point may, therefore, be regarded as a probable intake zone for the movement of cold air off the hillside.

Instruments

The stations instrumented and the levels at which the instruments were placed are shown for each year (table 1). The instrument profiles were

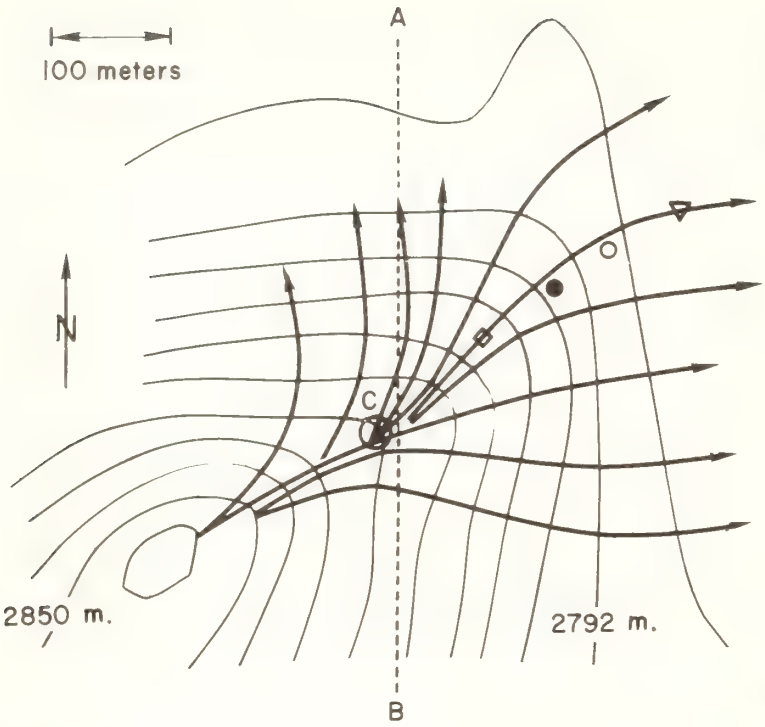
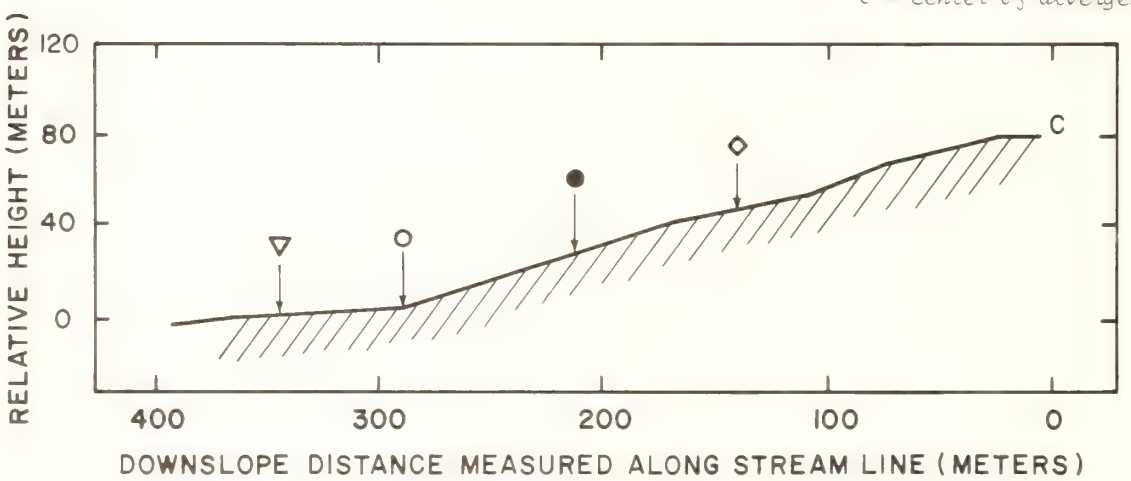


Figure 1.--

A - Contour map with estimated streamlines and measurement stations, Fraser River valley, Colorado.

B - Altitude cross section of transect. C = center of divergence.



placed approximately between trees, with each profile having at least 5 m. of clear fetch up the slope.

Air temperatures were measured with precision bead thermistors, mounted on 1-m.-long arms that extended across slope from the nearest tree stem and well away from foliage. The nominal resistance of these beads is 10 KΩ, high enough so that thermal effects even along a considerable length of cable were negligible. The thermal time constant of these beads is about 2 seconds, but smoothing was provided by radiation shields which enclosed each bead. For the first 2 years, these were of folded aluminum. In 1966, a half-closed styrofoam cup was used as a shield. The time constant with moderate ventilation was on the order of a minute.

At the tower near the slope base (T in fig. 1), shielded thermocouples were used at the 0.5-, 2.5-, 5.0- and 15.0-m. levels. In 1962 and 1964, temperatures at the 0.3-m. level on the slope were measured with bimetal thermographs. One of these instruments was also located in a screen at a height of 3 m., about 100 m. to the east of the base tower in 1964 and 1966.

Table 1.--Stations measured and levels on slope at which instruments were placed, 1962, 1964, 1966

Year	Stations measured	Location of instruments								
		Air-temperature levels								Other
		- - - Meters - - -								
1962	I[1]	0.3	1.7	5.0						
	II[1]	.3	1.7	5.0						
	III	.3	1.7	5.0						
	IIIb	.3	1.7	5.0						
	IV[1]	.3	1.7	5.0						
	Tower	1.3	2.5	5.0	10.0	20.0				
1964	I	.7	6.0	7.0	9.0	12.0				Surface pressure
	III	.7	10.0	12.0						Surface pressure
	IV	.7	2.3	4.3	6.0	8.3				Surface pressure
	Tower	1.3	2.5	5.0	10.0					Total radiation
	Screen	3.0								
1966	I	.5	1.8	3.9	14.0					Surface pressure
	III	.4	1.7	3.1	5.9	7.4	8.7	10.2	14.6	
	IV	.3	1.5	3.0						Surface pressure
	Tower	1.3	2.5	5.0	5.9	10.0	11.4	20.0		Total radiation
	Screen	3.0								

[1]Two profile stations 20 m. apart on either side of the transect.

The nominal observation period for all years was 1800 local standard time (LST) to 0600 LST of the following day. Observations were begun only on clear afternoons, and when the 20-m. tower wind was less than 0.5 m. sec^{-1} at 1800 LST. However, conditions often changed during the night; August 25, 1962, was relatively cloudy by 2000 LST.

In the 1962 observations, the thermistor resistances were measured with a manually operated bridge circuit and a plug board; temperature profiles at stations Ia, IIa, IVa, and Ib, IIb, IVb were read every 20 minutes. The output of the tower thermocouples was recorded automatically at 12-minute intervals. For the 1964 and 1966 observations, all temperatures except at the bimetal thermograph positions were measured and recorded automatically at 12-minute intervals.

Total radiation was measured with a ventilated radiometer whose output was recorded at 12-minute intervals during observation periods. Occasional checks were made for signs of dew or frost on foliage or slope surface. None was observed for any of the nights.

Pressure variations on the slope were recorded on aneroid microbarographs.

Vertical Temperature Profiles

The most detailed vertical temperature profiles in the observation set were those measured at station III, called the "midslope station" below, in 1966. A typical midslope station profile is shown in figure 2. This profile is based on the 2-hour average of air temperature from 2400 LST on the observation night of June 15, 1966. The lowest temperatures and strongest vertical temperature gradients appear at the slope surface, as would be anticipated if the latter functioned as a principal heat sink. The vertical gradient decreases sharply above the first meter of height, to the region from 4 to 6 m., increases, and then vanishes at an inversion at about 7 m. height where the temperature shows a local maximum. Higher temperatures are not attained on the profile below a level of 11 m. height. This layer of air is statically unstable; that is, a relatively warm layer is underlying a colder layer of air.

The entire cooled layer at this station extends to about 30 m., as judged from the temperature drop from the 1800 LST profile and the pressure increment from that time indicated by the micro-

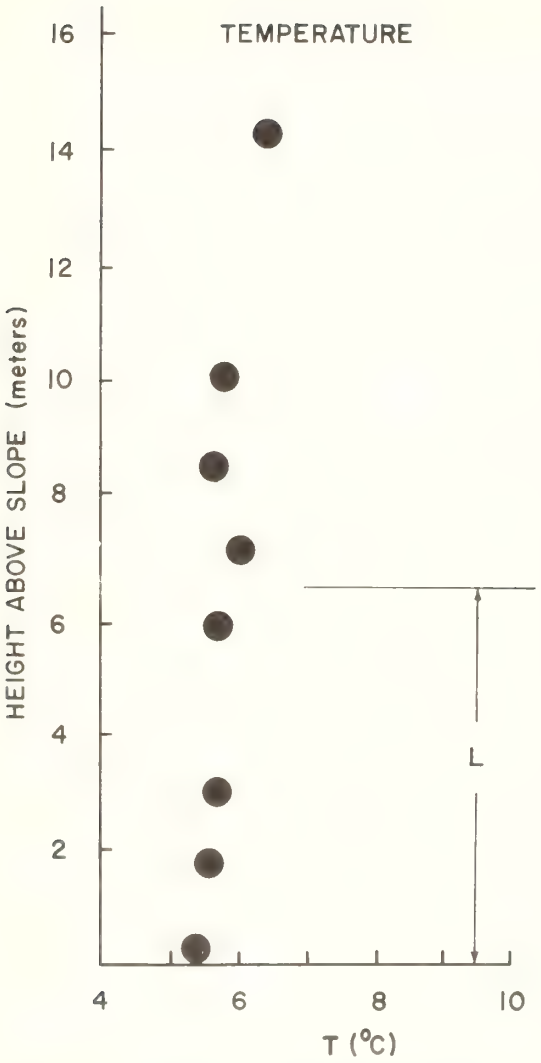


Figure 2.--Midslope station temperature profile, Station III, June 15, 1966, 2400-0200 LST. L = height of first inversion above slope.

barograph trace. The height of the first inversion above the slope is labeled (L) on figure 2, and will be referred to in the subsequent analysis of the temperature data.

The most interesting feature of the profile is obviously the warm layer at the first inversion. This feature occurs in the temperature measurements presented by Geiger (1958). His measurements were vertical profiles of air temperature along a strip cut down the side of a conifer-covered mountainside, and they are in most respects comparable to those described in this paper. His measurements were taken at various positions along a geometrical transect of the mountainside, however, which may not have had any direct relation to the pattern of air movement from the slope. Geiger's measurements indicate an "altitude of maximum temperatures," which separates the vertical temperature profiles into two types. The lower region shows a warm zone below the treetops, quite analogous to that found on figure 2 for the Fraser measurements; the upper region does not.

Variation of Temperature with Downslope Distance

A characteristic temperature which can be readily defined from the vertical temperature profiles of the 1966 observations, and which can be estimated from the observations of both the preceding years (1962 and 1964) is the average temperature ($\bar{T}$) of the air layer below the height (L).

This average was computed on the assumption that (L) was approximately the same for all the nights of observation, with a value of 7 m. at the midslope station III, 10 m. at the tower station, and 8 m. at station I. The value of (L) at the intermediate stations was interpolated from these points. As seen from the relatively small temperature gradients near (L), this average temperature is not particularly sensitive to differences of the order of 1 m. in the assumed value of (L).

The hourly average of this temperature is plotted for each of the 13 nights of observation (fig. 3).

At the beginning of the evening—1800 LST—the temperatures either show a decrease or no variation down the transect. Six of the nights show no variation. A somewhat more irregular pattern is evident for September 17 and 25, 1964, and June 14, 1966. On September 17, a definite temperature maximum occurs on the slope at the vicinity of station III, which persists well into the evening. On September 25, a temperature minimum is evident near station IV, which vanishes near midnight and reappears the following morning. This effect may reflect a relatively uncommon large-scale stratification over the Fraser River valley.

In general, the temperature pattern for the night may be divided into two periods similar to those

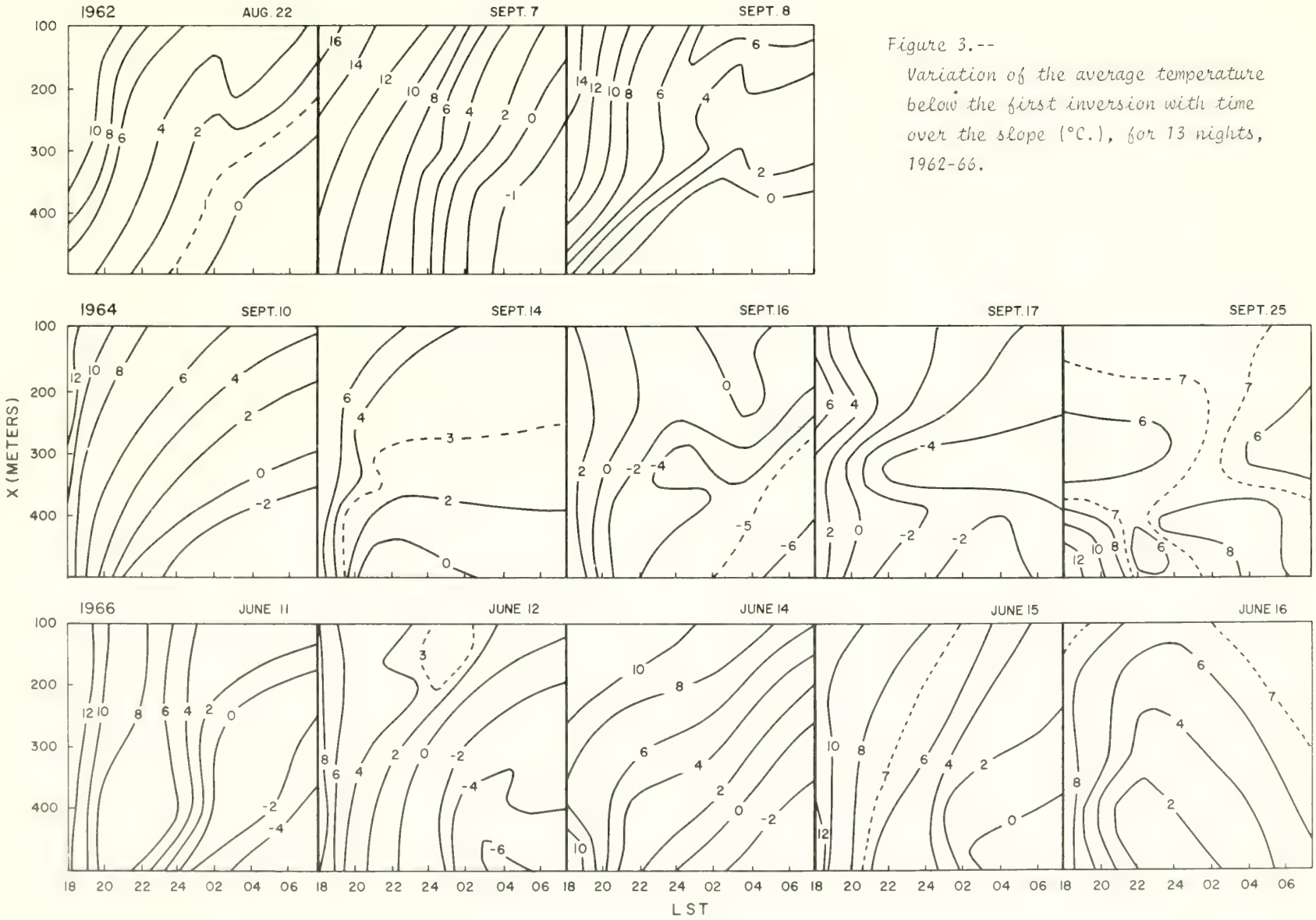


Figure 3.--
Variation of the average temperature below the first inversion with time over the slope (°C.), for 13 nights, 1962-66.

found in the study by Leighton (1954)—a period of uniform cooling over the entire slope with a relatively constant temperature gradient down the slope, and a period of increasing downslope gradient with little temperature change near the crest of the hillside (point C).

On some nights, for instance June 11, 1966, the second phase does not seem to occur. On others, notably June 15, 1966, the first phase does not appear within the period of observation; the crest temperature remains constant throughout the night. For most of the nights, a smooth transition between the two modes of cooling occurs at about midnight. A feature conspicuous by its absence is a "warm altitude belt," that is, an intermediate altitude at which a persistent temperature maximum is found on the slope. Local temperature maxima do occur for many of the nights, but they are transient and appear to be frequent at no one altitude level on the slope.

The "warm belt" or "altitude of maximum temperature" mentioned above has been observed in many studies, and the available literature is discussed in detail by Geiger (1957). One notes that the "warm altitude" belt tends to be regarded as a two-dimensional feature: some particular altitude on the slope. Regarded as such, it becomes a rather mysterious phenomenon. If the three-dimensional character of the cold airflow on most mountains is considered, however, such an altitude zone becomes possible as a consequence of the way in which a particular geometrical altitude transect is drawn relative to the estimated streamline pattern. This point was apparently first noted by Hayes (1941). Thus, a line (AB) can be drawn on figure 1A with a continuous increase in altitude which would probably show a definite "warm belt." This "warm belt" would reflect the fact that the air on the upper portion of the transect beyond point (C) would have been in contact with the surface heat sink for a much longer period of time than the air below (C); in other words, they originate at different intake zones. Note also that the importance of divergence centers such as (C) would not be apparent from a two-dimensional cross section of a slope. While they may appear as regions in the two-dimensional cross section of low slope, or "shelves," such shelves could be zones of convergence or divergence, depending on the sense and magnitude of the height contour curvature.

Short-period pulsing in the temperature field is found in the observations, particularly for August 22 and September 8, 1962, and September 16, 1964 (fig. 3). For August 22 and September 8, which are more clearly defined, pulse amplitude appears to decrease downslope, yet there is no detectable phase shift or change in period. The effect seems to be associated with the shift in the cooling pattern mentioned above. Since the nights of September 9, 1964, and June 12, 1966, began with an isothermal hillside, it cannot be said that pulsing is associated with a large lapse rate outside the cooled layer on the slope, as might be inferred from the 1962 data. Also, the position of maximum pulse amplitude on the hillside appears to vary between the nights.

Radiation

As shown by some direct measurements in 1964, (Bergen 1969), the net radiation above the canopy at a point on the slope averaged over the night is fairly well approximated by the average difference between the sky radiation measured at the base of the slope and the black body emission, which corresponds to the mean air temperature measured in the canopy. Assuming that such an estimate may be used for 2-hour periods, the net radiation for those intervals was estimated from the radiometer readings and the associated averages of the measured air temperatures in regard to time, height above the slope, and position along the transect, for the 5 nights of 1966 (table 2).

Sky radiation fell steadily through all the nights with the exception of June 16. There is more variation in the pattern of computed net radiation losses, including uniformly increasing values for June 11 and minima for various hours in the remaining nights. Comparison with the 1966 plots (fig. 3) indicates no clear relation between the time of such minima and the transition between the two modes of cooling mentioned above.

Variation of Potential Temperature along the Transect

The temperature drop along the hillside transect does not directly indicate the decrease in enthalpy of the air moving down the slope. Due to com-

Table 2.--Two-hour averages of sky radiation and estimated net radiation loss, 1966

Date	Time LST	°C. $\bar{T}_m$	Ly Min.$^{-1}$ R_B	Ly Min.$^{-1}$ Rsk	Ly Min.$^{-1}$ R_o
June 11	2000	8.6	0.404	0.404	0.110
	2200	6.9	.374	.374	.128
	2400	2.0	.335	.335	.132
	0200	- .2	.321	.321	.132
June 12	2000	5.8	.494	.412	.082
	2200	5.4	.491	.385	.106
	2400	3.4	.477	.342	.135
	0200	.7	.459	.319	.140
June 14	2000	9.7	.522	.379	.143
	2200	8.8	.515	.383	.132
	2400	8.4	.512	.377	.135
	0200	6.7	.497	.340	.157
June 15	2000	8.3	.512	.399	.113
	2200	7.9	.509	.442	.067
	2400	6.4	.498	.395	.103
	0200	5.0	.488	.387	.101
June 16	2000	8.6	.498	.391	.107
	2200	6.4	.498	.419	.079
	2400	5.2	.489	.392	.097
	0200	6.2	.497	.398	.099

pressibility, downward movement of air along an isothermal hillside would correspond to an appreciable energy loss, the amount depending on the change in altitude and thus the mean atmospheric pressure from point to point on the flow.

"Potential temperature" directly reflects the enthalpy losses of the air on the slope. The potential temperature may be defined as the final temperature of a unit mass of air which is compressed to a pressure of 1,000 mb. without energy loss or gain, and without a change of phase in the water contained in the air.

The use of 1,000 mb. as the reference pressure is arbitrary, and in the case of the experimental hillside, it is more convenient to use the standard atmosphere pressure at point (C). Thus, since (C) is about 90 m. above the tower station, we would subtract 0.9° C.—90 m. times the adiabatic lapse rate of 0.98° C. per 100 m.—from the temperature at the tower station to obtain the potential temperature θ.

When this transformation is applied to the base average temperatures ($\bar{T}$) as previously calculated we obtain a corresponding average potential temperature $\bar{\theta}$, which is plotted (fig. 4) for 2-hour intervals for each of the nights against the downslope distance (X) measured along the streamline of figure 1A from point (C).

The potential temperatures plotted in figure 4 correspond to 2-hour averages of ($\bar{T}$) and show a more regular trend, in particular the temperature drop is close to linear on the slope itself, that is, for X less than 400 m. The pulses evident in the previous figures are almost totally smoothed out.

The two patterns of cooling are more evident in figure 4 than in figure 3, as is the significance of point (C), particularly on June 12 and June 15. A linear extrapolation on these nights would yield an almost constant temperature at (C), although the temperature at the base of the slope drops as much as 10° C. through the night. Temperature at point (C), then, is a function of the potential temperature field above the cooled layer on the hillside, while the potential temperature drop along the streamline depends primarily on the net radiation loss along the hillside.

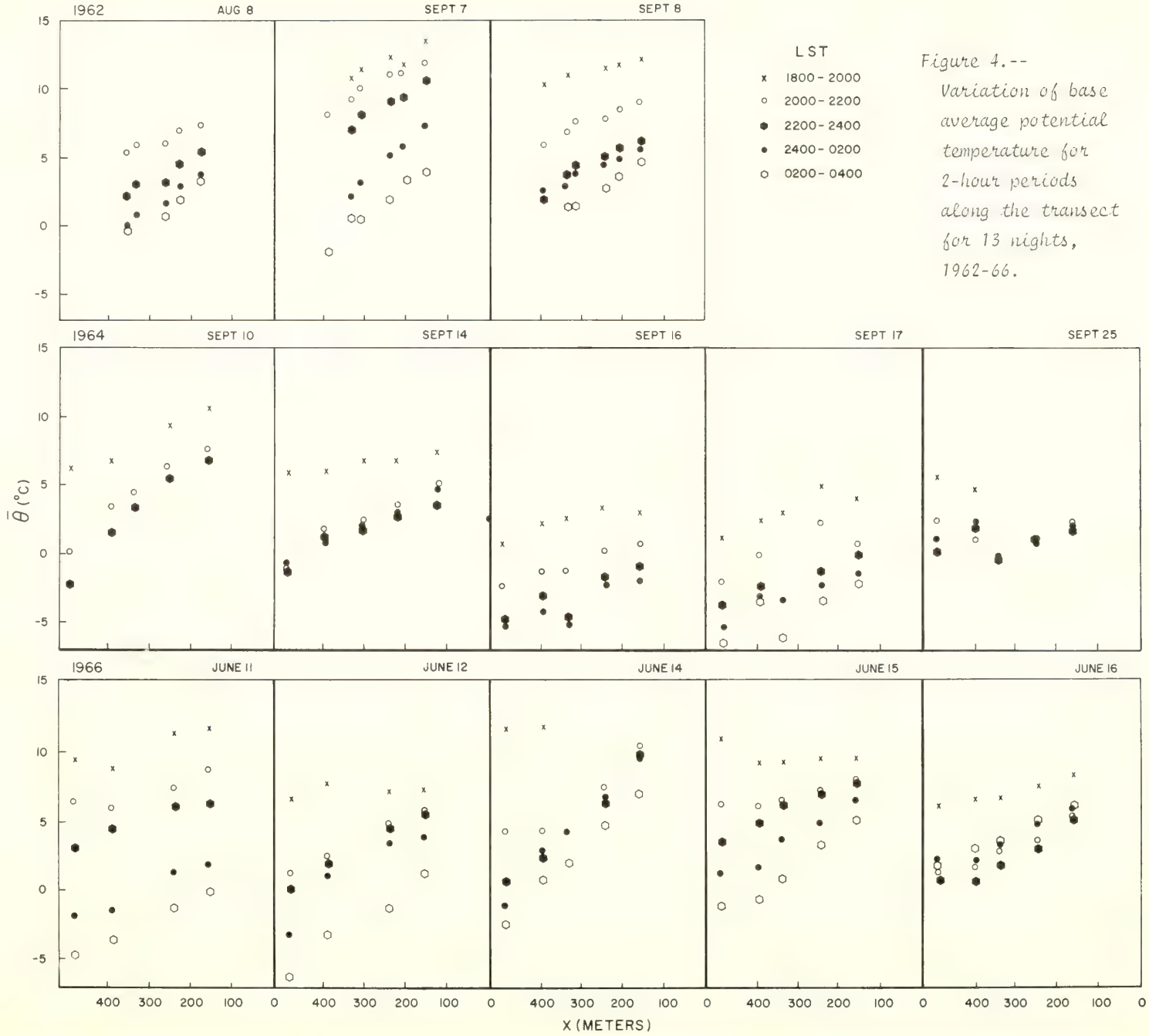


Figure 4.--
Variation of base average potential temperature for 2-hour periods along the transect for 13 nights, 1962-66.

The data presented in figure 4 have a direct bearing on an assumption basic to many analytical solutions for the motion of cold air on a hillside. Most of these solutions involve what may be called a "perturbation assumption" in regard to the sensible heat advected along the slope by the drainage flow. The temperature drop along the slope is assumed to be small in relation to the drop in temperature with height in the air above the slope. The most extreme assumption is that the slope is uniformly cooled, which is the case first treated by Prandtl (Sutton 1953).

This assumption is quite distinct from the basic "pressure perturbation" assumption: that the pressure change on the slope is small relative to the total atmospheric pressure, which is easily defended and was in fact made above in evaluating the potential temperatures plotted in figure 4. It may be seen that the downslope gradient for either the potential temperature or the temperature field itself is at least the order of 2 to 10 times that on the hillside at the onset of cooling, and far greater than would be anticipated for the free atmosphere over the valley at sunset.

Composite Potential Deficit Profiles

There are many points in common between the flow of cold air from a hillside and free convection phenomena observed in the laboratory, such as the ascent of air over a vertical heated plate. Such laboratory flows are often found to exhibit "similarity" in both the velocity and temperature distribution.

The notion of similarity as applied to the case of cold air drainage off such a slope and referring to the potential temperatures on the slope is equivalent to assuming that some characteristic potential temperature (θ_s) and some length (L_s) exist, which are functions only of downslope distance (X) from the origin of the flow measured along the streamline, and are such that ($\theta - \theta_o$) at any level above the slope (Z) conforms to the relation:

$$\theta - \theta_o = (\theta_s - \theta_o)\, f(Z/L_s)$$

where θ_c is the potential temperature at point (C).

While many choices are possible for θ_s and L_s, the average potential temperature below the first inversion above the slope ($\bar{\theta}$) discussed above must be a legitimate scaling temperature if such exists. The most accessible length is the height of the first inversion above the slope, which has been denoted as (L) above.

While such scaling would appear sufficient for a bare slope, the temperature measurements discussed were made in a random array of trees. The streamlines (fig. 1A) must have relevance to the actual movement of air only as a spatial average over lengths of the order 20 m. or so. The situation is in many respects analogous to flow in a porous medium, with the spaces between trees on the slope being analogous to the pore spaces. Since the radiating foliage is the primary heat sink for at least the portion of the airflow above the first inversion, (Z = L), there must be a temperature drop from the center of these spaces to the foliage surface of the trees. Unfortunately, foliage temperatures were not measured directly during the observation. The 1962 measurements do show that the air temperature measured between trees does not vary appreciably between stations some 20 m. apart at the same downslope distance from the origin; the average difference between such stations was less than 0.3° C. Thus, the approximate linearity of the potential temperature $\bar{\theta}$ shown on the transects (fig. 4) is apparently more than an artifact of the choice of stations.

The apparent height scales for June 14, 15, and 16 are 11m., 7 m., and 10 m. for the stations I, III, and the tower station, respectively. The scale for station IV was taken as 9 m., an intermediate value between that for station III and the tower station and in accord with the relative position of the inversion at station IV found in the 1964 observations.

The apparent height scale (L) for the nights of June 11 and 12 is less by about 15 percent—about 6 m. at the midslope station. The scale was assumed to be less by the same proportion at the remaining stations, although the variation at these less densely instrumented profiles was not as clear.

The number of data levels at each station varied between observation periods, with most of the levels above (Z = L) inoperative during the first night, June 11.

Even at the densely instrumented stations at the tower and at midslope, (L) could not be resolved to within less than a meter; the estimates for stations I and IV are thus even more conjectural. The temperature (θ_o) at the point (C) was estimated by linear extrapolation from the values of $\bar{\theta}$ at the stations on the slope (fig. 4).

The results of a composite plot of (Z/L) versus

$$\frac{\theta - \theta_o}{\bar{\theta} - \theta_o}$$

for the 1966 observations are shown in figure 5 for all stations. The plots are for 2-hour average temperatures, with the individual station's data coded in the legend.

The hypothesis of similarity as stated in the equation above would require that these profiles for the individual stations superimpose.

The plots suggest this is the case for most of the intervals of measurement. In evaluating the superposition, it must be noted that the nominal accuracy of these temperature measurements is about ±0.5° C. at all stations on the slope. Since θ decreases appreciably down the transect, this would imply a much larger relative error for station I than for the tower station.

Below the first inversion, superposition is within 10 percent at all levels between the stations. Above the first inversion, the superposition is of more variable quality, but still within 20 percent.

To compare the composite profiles for different intervals of observation on the same night and between nights, a pair of polynomial segments were fitted to the profile for the last three profiles of June 15. These segments are shown by the dashed lines on the plots for all the observation intervals of June 12, 14, 15, and 16. For most of the intervals, the deviation from this fitted profile is nonsystematic and amounts to not more than 20 percent.

For the observations of June 11 and 12, the reduction of scale length appears to be associated with a relative expansion of the warm layer above the inversion. While the deficiency of the upper-level data for June 11 makes comparison with the profile fitted to the June 12 observations doubtful, the superposition appears satisfactory below (Z = L).

The approximate validity of the similarity assumption is more than a curiosity, and can serve as a valuable tool in the quantitative analysis of the temperature regime on the slope, as shown by Katkov (1965). The polynomial segments that appear to yield a plausible fit to the scaled potential temperature deficit profiles are of low order: a parabola below ($Z/L_{-} = 1$), and a cubic equation above that level with the physically plausible boundary conditions of a vanishing gradient at (Z = L), and zero deficit at (Z = 2.3L).

Conclusions

The nocturnal temperature distribution on nonuniform slopes reflects the three-dimensional movement of air off these slopes, both in the spatial variation of the average temperatures of the active layer of air, and in the vertical variation of air temperature through that layer. In such situations, the geometrical summit of a slope may be less relevant than the centers of divergence for flow on the slope computed on the assumptions of continuity and that the flow is normal to the elevation contours.

On the simple slope studied, the potential temperature profiles along an estimated streamline show approximate similarity.

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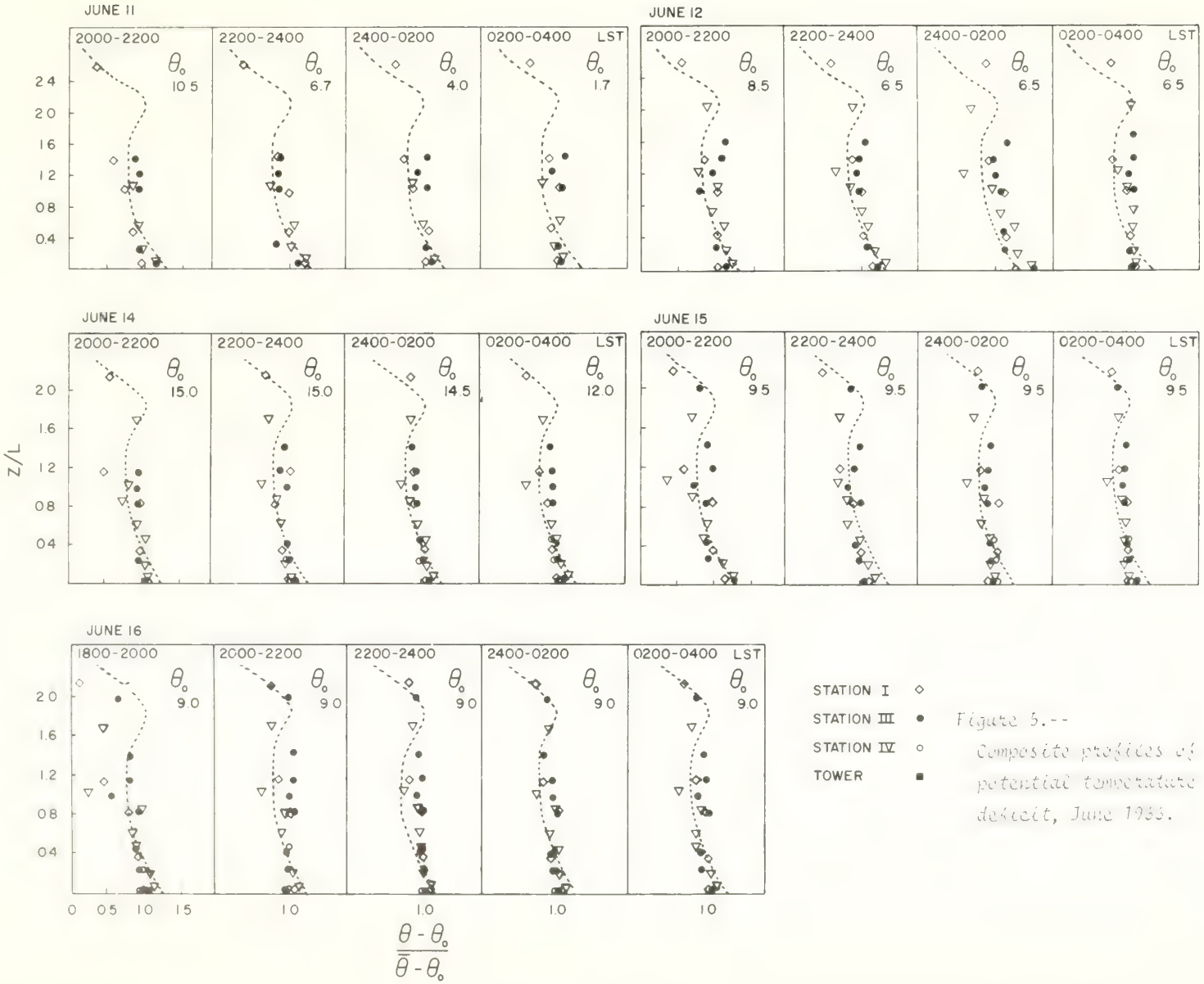

Figure 5.--
Composite profiles of potential temperature deficit, June 1966.

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Bergen, James D.
1969. Nocturnal air temperature on a forested mountain slope. USDA Forest Service Research Paper RM-52, 12 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

Profiles of air temperature on a forested mountain slope show an inversion below the top of the tree canopy. The slope tends to cool with constant downslope temperature gradient in the early part of the night; gradients increase in the later hours. Plots of potential temperature indicate, for some nights, a point of almost constant temperature halfway up the hillside. This point can be identified with a center of divergence for cold air moving off the slope. The potential temperature deficit relative to the temperature at this point shows approximate similarity between vertical profiles at the different stations when the profiles are scaled by the height of the first inversion above the slope and the average potential temperature deficit below that inversion.

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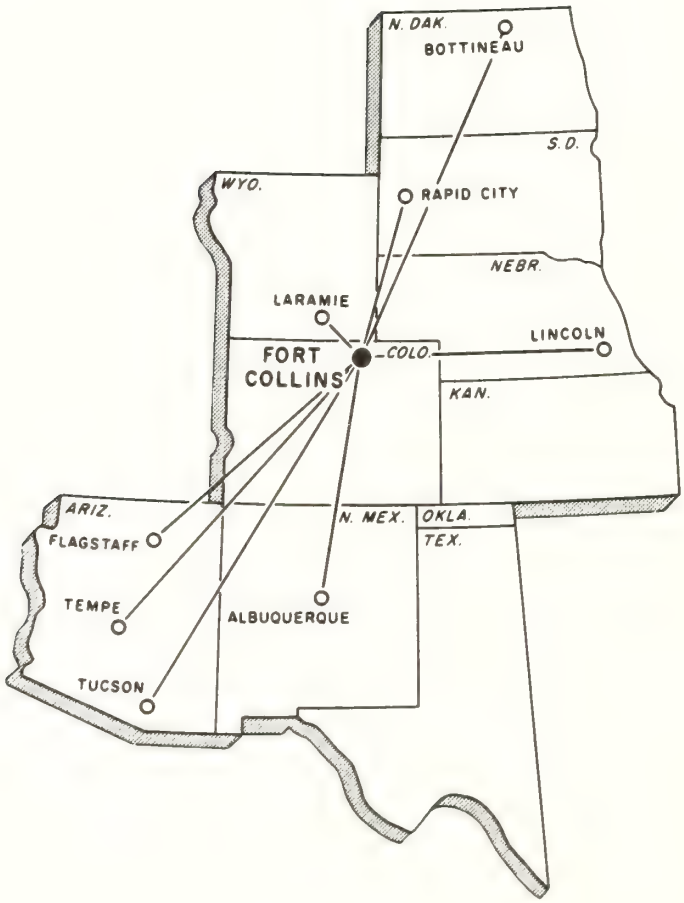
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Seedfall and Establishment of Engelmann Spruce in Clearcut Openings: A CASE HISTORY

Robert R. Alexander

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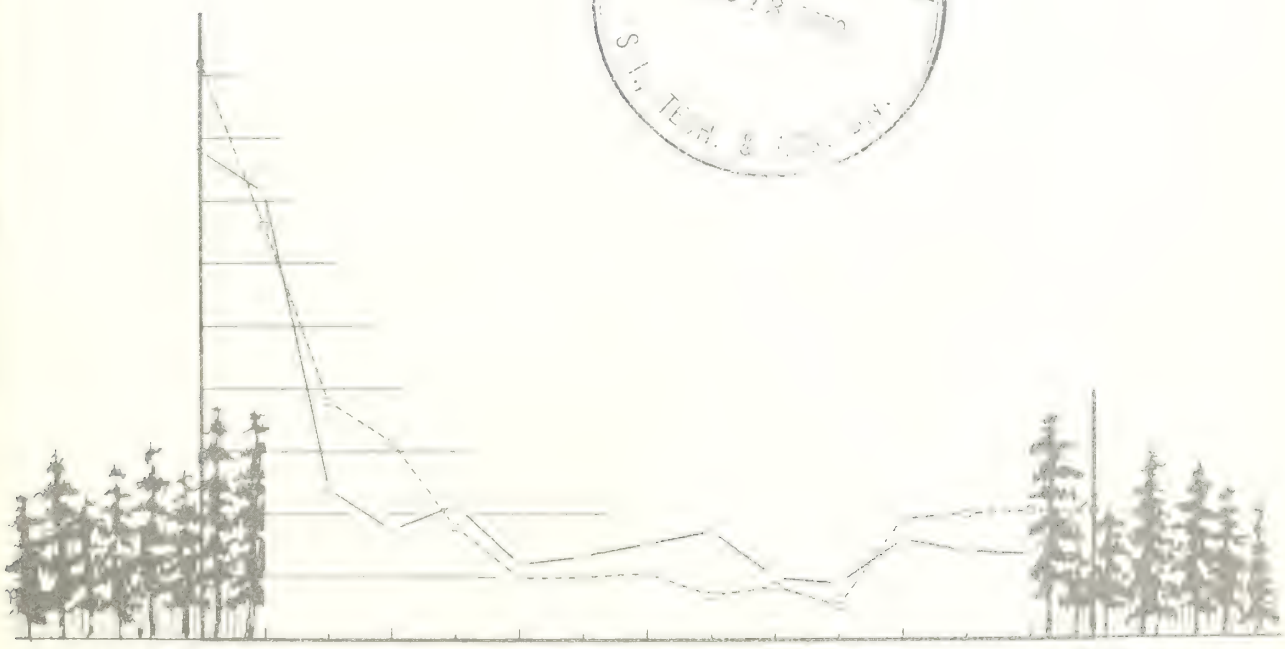

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U. S. Department of Agriculture Forest Service
Fort Collins, Colorado

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Research Paper RM-53

1969

Seedfall and Establishment of Engelmann Spruce in Clearcut Openings: A CASE HISTORY

by

Robert R. Alexander, Principal Silviculturist

Rocky Mountain Forest and Range Experiment Station[1]

[1]Central headquarters maintained at Fort Collins, in cooperation with Colorado State University.

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Seedfall and Establishment of Engelmann Spruce in Clearcut Openings: *A Case History*

Robert R. Alexander

Prompt establishment of new stands of spruce following timber harvesting is a major objective in the management of the Engelmann spruce-subalpine fir type in the central Rocky Mountains. Although planting has increased in the past decade and is expected to continue to increase, it will not be economically possible to plant at the rate at which spruce-fir forests will be cutover. Natural reproduction must therefore be depended upon to restock most clearcut areas

An adequate supply of viable seed, a receptive seedbed, and an environment favorable to germination and seedling establishment are the basic elements necessary for successful natural regeneration. Most spruce regeneration problems have been thought to be related to environmental factors influencing germination and survival success. However, recent studies and observations have indicated that seedling establishment is limited to the margins of clearcut openings—usually 1 to 2 chains from seed source.[2] Roe and Schmidt[3] reported similar results from a survey of seedling establishment in the spruce-fir type in the Intermountain Region; few seedlings became established at distances greater than 3 chains from the seed source.

If the limited distribution of seedlings on clearcut openings is the result of lack of viable seed, more information is needed on seed production and dispersal before spruce cutovers can be successfully restocked to natural reproduction. Good seedbed situations and favorable environmental conditions are of little value if an adequate amount of viable seed is not available.

Engelmann spruce has been rated as a moderate seed producer. The seed is light and is dispersed long distances.[4] Spruce seed production and dispersal have been studied in only a limited way in the Rocky Mountains, however.

In one of the earliest studies in Colorado, Bates and Roeser[5] found that the average annual production on the White River Plateau for an 18-year period (1914-31) was 83,000 sound seeds per acre, while on the Uncompahgre Plateau, annual production for a comparable 15-year period (1914-28) averaged 350,000 sound seeds per acre. Large crops (100,000 or more sound seeds per acre) were produced on the White River only at 5- to 7-year intervals, with complete failures about every 2 years. On the Uncompahgre, large crops were produced every 2 to 4 years, with complete failures at about 3-year intervals.

Boe[6] analyzed seed records in Montana between the years 1908 and 1953. He reported data separately for the areas east and west of the Continental Divide. West of the Divide, 22 crops observed during the 45-year period were rated as 5 good,

[2] *Unpublished data on file at Rocky Mountain Forest and Range Exp. Sta., U.S.D.A. Forest Serv., Fort Collins, Colo. 80521.*

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8 fair, and 9 poor. East of the Divide, seed production was considerably poorer: only 2 good, 4 fair, and 15 poor crops were reported for a 21-year period. Throughout Montana, 1926 and 1952 were exceptionally good spruce seed years, but only the 1952 crop was heavy throughout the Rockies.

Squillace [7] estimated that about 953,000 seeds per acre were produced in 1952 in an uncut stand along the perimeter of a large clearcut area in western Montana. Furthermore, he showed that a substantial number of sound seeds (60,000 per acre) were dispersed as far as 9 chains from the timber edge. However, this wide dispersal was during an infrequent "bumper" seed year. Seed crops produced in the other 4 years of his study (1949, 1950, 1951, 1953) were considered failures.

Roe [8] studied seed production and dispersal on three areas in the Intermountain Region. Production in uncut stands along the edge of clearcut openings in a good seed year (1964) ranged from 200,000 to 2 million sound seeds per acre. Although large quantities of seed were released at the timber edges, less than 5 percent were dispersed as far as 10 chains into the openings. The pattern of seed dispersal was quite similar on all areas, except for quantitative differences that were attributed to differences in seed sources.

Current studies of seed production and dispersal on five National Forests in Colorado[9] show that average seedfall in uncut stands along the perimeters of clearcuts, 1962-66, could be rated good about 1 out of the 5 years. Furthermore, most of the seed dispersed into the clearcut openings fell within 1 chain of the source.

Study

This paper reports the results of a study of seed production, dispersal, and seedling establishment after clearcutting in the spruce-fir type on Fool Creek, Fraser Experimental Forest, Colorado.

[7] *Squillace, A. E. Engelmann spruce seed dispersal into a clearcut area. U.S.D.A. Forest Serv. Intermountain Forest and Range Exp. Sta. Res. Note 11, 4 pp., illus. 1954. (Ogden, Utah 84401)*

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[9] *See footnote 2, p. 1.*

Description

The study was located in two 6-chain-wide clearcut openings—each approximately 3.5 acres in size—at 10,500 feet elevation. All trees 4.0 inches d.b.h. and larger had been removed in logging. To eliminate any internal seed source, residual trees large enough to bear cones were also cut on the study areas after logging was completed in 1956.

One opening is on a gentle north-facing slope; the other on a moderate northwest slope. Wind records taken at 10,500 feet on the west ridge of Fool Creek indicate that the prevailing winds in the study area are from the west and southwest. The openings are oriented approximately at right angles to these winds.

The uncut stand of timber adjacent to the clearcut openings is mature to overmature—250 to 300 years old—Engelmann spruce (Picea engelmannii Parry) and subalpine fir (Abies lasiocarpa (Hook.) Nutt.), intermixed with various amounts of old-growth lodgepole pine (Pinus contorta Dougl.). Spruce makes up about 60 to 80 percent of the basal area in trees 10.0 inches d.b.h. and larger.

Methods

Quantity of seed produced and distance of dispersal were measured with seed traps. In each clearcut opening, fifteen 0.25-milacre seed traps were placed along each of two parallel transect lines about 2 chains apart and approximately at right angles to the windward timber edge. The traps in each transect were placed at 0.5-chain intervals beginning 0.5 chain into the uncut stand on the windward edge of the openings and ending 0.5 chain into the uncut stand on the leeward side (fig. 1). The placement of traps permitted an estimate of (1) seed production in the uncut timber stand and at the timber edge on both the windward and leeward sides of the openings, and (2) seed dispersal at intervals across the openings.

Seed trap contents were collected in early summer annually, 1956-65. All seeds collected were cut to determine soundness. Only filled seeds that appeared to be sound were counted.

Seedling survival in each opening was measured on 52 plots. Paired milacre quadrats were established at each seed trap location except in the uncut stands. One randomly selected quadrat of each pair was scarified to mineral soil; the other

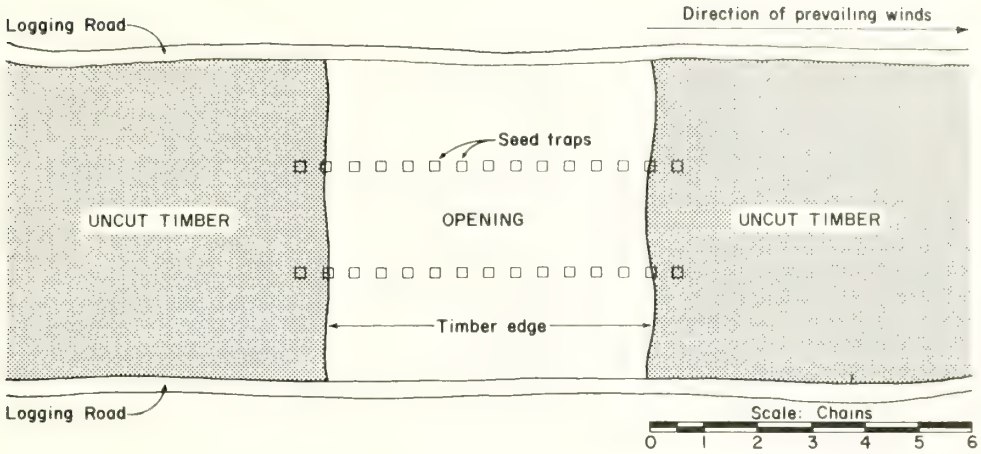

Figure 1.--Diagrammatic sketch of study plot layout.

was left untreated as a control. Seedlings were counted annually in the late summer beginning in 1958. Only seedlings that had survived 2 growing seasons were tallied. Seedlings were not marked to indicate the time of establishment; seedlings surviving at the time of the last tally in 1967 varied, therefore, from 2 to 12 years of age.

Analysis of Data

Annual seed count data for each aspect were stratified into fifteen 0.5-chain-wide zones, beginning 0.5 chain into the timber stand on the windward side of the openings. Seed count data were plotted by 0.5-chain intervals for (1) individual years—when enough seeds were caught to make comparisons, (2) the 10-year (1956-65) average, and (3) the average for the three most productive years (1959, 1961, and 1963). No differences were apparent between aspects in either the quantity of seed produced or the amount of seed dispersed into the openings (figs. 2, 3).

The number of seeds caught under stands—leeward and windward sides of the openings on both aspects—was compared with the number, basal area, and average diameter of all spruce trees 10.0 inches d.b.h. and larger growing in those stands. No significant relationship could be established, however, between the quantity of seeds caught under the timber stands and any of the variables measured to characterize the seed source.

Seedling survival data for 1967 from each study area were stratified into thirteen 0.5-chain-wide zones, beginning at the windward timber edge. Only data from the scarified seedbeds were used because too few seedlings became established on the control plots to make any comparisons. The number of seedlings and percent of stocked milacres were plotted over zones. The resulting scatter diagrams indicated that there were no substantial differences in seedling survival data between the two areas.

Those preliminary tests suggested that the seed count and seedling survival data from the two aspects could be combined. The combined data were stratified as before. Differences in seedfall and number and stocking of seedlings between zones were tested by analysis of variance and Duncan's multiple range tests with appropriate transformations.

To estimate seed dispersal in relation to seedfall under stands and distance and direction from source, the seed count data for 1959, 1961, and 1963—seedfall was too light or erratic to determine the dissemination pattern in other years—were plotted over distance from windward source by 0.5-chain intervals. Smooth curves were fitted to the resulting distribution for each of the 3 years.

Results and Discussion

Seedfall

Production (under stands).—Numbers of sound spruce seed caught under stands appeared to be

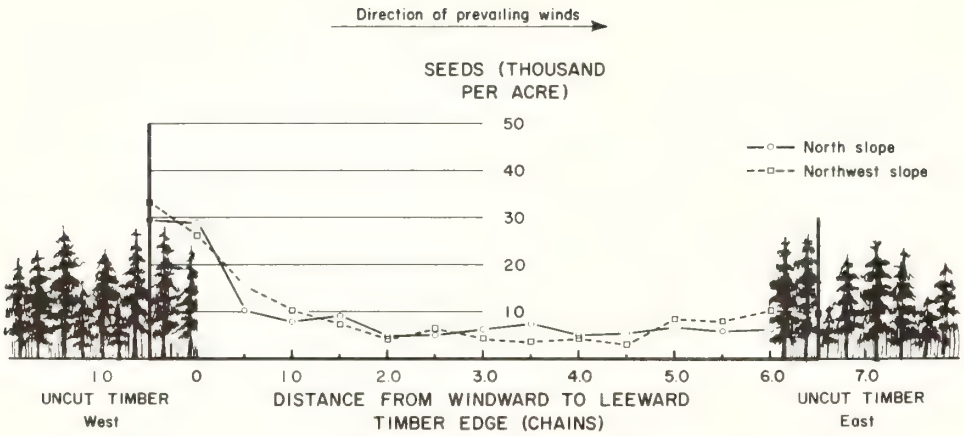

Figure 2.-- Average 10-year dispersal of sound Engelmann spruce seeds into clear-cut openings on N and NW aspects in relation to distance from windward timber edge.

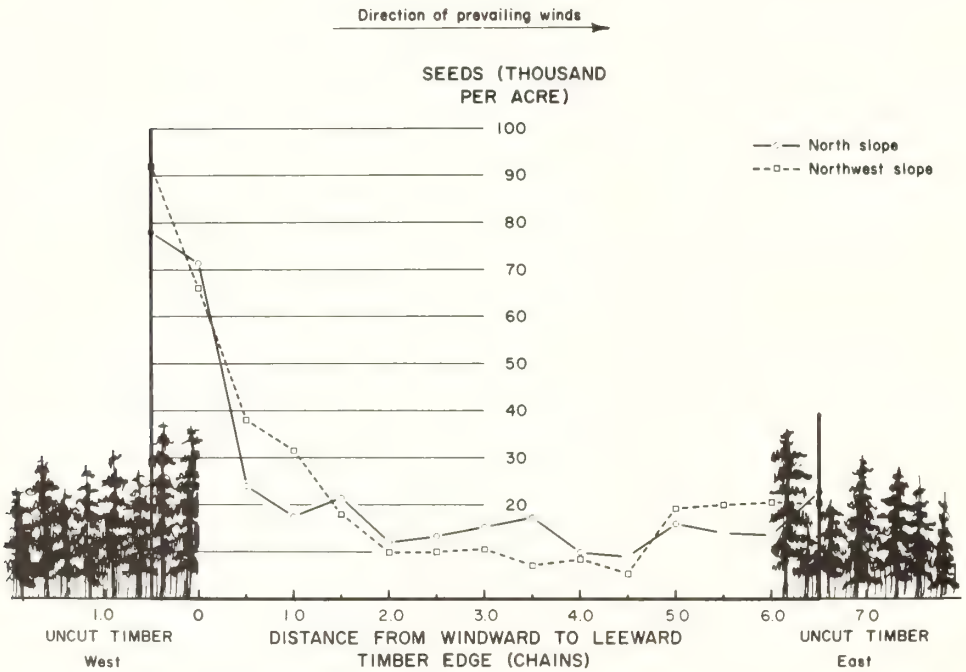

Figure 3.-- Average number of sound Engelmann spruce seeds dispersed into clear-cut openings on N and NW aspects during the three most productive years in relation to distance from windward timber edge.

influenced more by the location of the stand with respect to prevailing winds than by any measured characteristic of the seed source. Average seed production was significantly greater under the stand on the windward side of the openings in years of both high and low seed production (table 1). Since traps were placed only 0.5 chain into the timber stands, fewer seeds caught under the leeward stand probably reflects the influence of wind movement across the openings; wind probably blew some seeds away from the leeward edge of the openings. Estimates of seed production under stands are based, therefore, on seedfall under the windward stand.

During the 10-year period 1956 through 1965, total under-stand seedfall was 321,000 sound seeds per acre. Annual seedfall varied considerably from year to year (table 1). The 1961 seed crop contributed about 40 percent of the total under-stand seedfall. Moderate crops (50,000 to 100,000 sound seeds per acre) were produced in 1959 and 1963. In the other 7 years of the study, seed crops were rated poor to nearly complete failures.

Table 1.--Average sound spruce seedfall under and at the edge of the timber stands adjacent to clearcut openings, Fool Creek study area, Fraser Experimental Forest, Colorado, 1956-65

Year	Windward side		Leeward side	
	Under stand	Timber edge	Under stand	Timber edge
	- - - - - Number per acre - - - - -			
1956	6,000	2,000	2,000	7,000
1957	6,000	10,000	0	3,000
1958	24,000	10,000	17,000	8,000
1959	64,000	55,000	23,000	24,000
1960	12,000	19,000	6,000	6,000
1961	133,000	128,000	25,000	23,000
1962	6,000	5,000	0	1,000
1963	55,000	24,000	18,000	5,000
1964	13,000	15,000	6,000	6,000
1965	2,000	2,000	0	1,000
Average	32,100	27,000	9,700	8,400

Dispersal (into openings).—Seed dispersal was influenced by the size of seed crop, distance from source, and direction and velocity of prevailing winds.

Seedfall into the clearcut openings was greater in years of heaviest seed production. About 35 percent of the total number of seeds falling to the ground in the openings were dispersed in 1961. An additional 35 percent were dispersed in the moderate seed years of 1959 and 1963.

Seedfall was not uniformly distributed over the openings, but decreased in an exponential manner as distance from source increased. Furthermore, most of the seed falling to the ground in the openings appeared to have been dispersed from the stand on the windward timber edge. About half of the total number of seeds dispersed during the 10-year period, and in each of the 3 years of moderate to good seed production, fell within 1.5 chains of the windward edge. Seedfall then either leveled off or gradually continued to diminish until about two-thirds of the way across the openings. The average number of seeds falling at that distance from source was about 10 percent of the under-windward-stand seedfall, regardless of the size of the seed crop. Beyond 4.5 chains, seedfall gradually increased until the leeward timber edge was reached (fig. 4).

The numbers of sound seed falling to the ground between windward timber edge and 1.5 chains into the openings decreased most rapidly in 1961—the year of highest seed production—but between 1.5 and 4.5 chains, the slope of the 1961 seed dispersal curve was similar to the 1959 curve (fig. 5). That suggests that differences in seedfall between windward timber edge and 4.5 chains in 1959 and 1961 were largely associated with differences in seed production.

Seed production was similar in 1959 and 1963, but seedfall in 1963 decreased more rapidly between windward timber edge and 1.5 chains into the openings (fig. 5). Furthermore, about the same amount of seed fell to the ground at 4.5 chains from source in 1963 as fell at 1.5 chains. Differences between seed dispersal curves for 1959 and 1963 suggest that velocity and perhaps direction of winds were different at the time seed was shed.

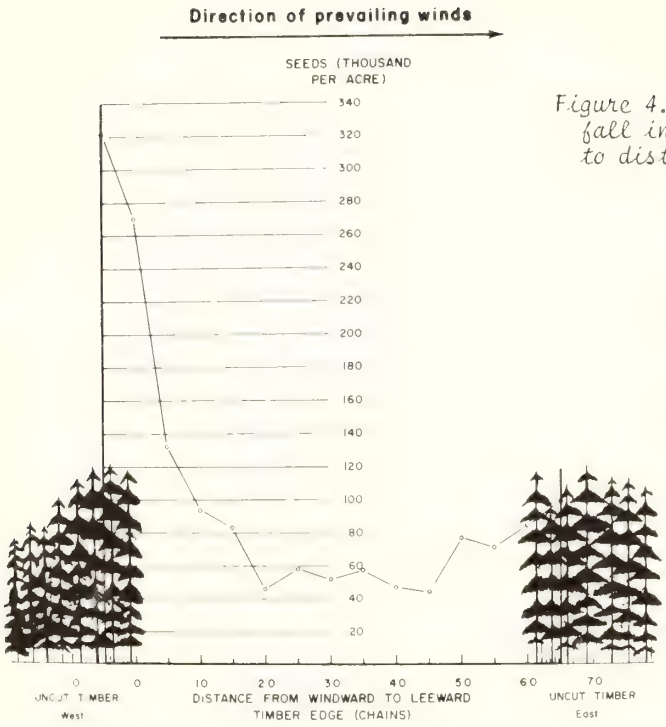

Figure 4.--Total 10-year Engelmann spruce seedfall into the clearcut opening in relation to distance from windward timber edge.

Fewer, but satisfactory, numbers of seedlings became established within 1 chain of the leeward timber edge (fig. 6). About one-fifth of the total seedfall into the opening occurred here. Those seedbeds were also shaded part of the time by the leeward timber stand, but they were exposed to the prevailing winds.

In the clearcut openings—between 1 and 5 chains from the windward edge—the number of surviving seedlings per acre ranged from 0 to 1,000, but only two zones contained more than 250 seedlings per acre (fig. 6). Fewer seeds fell into the openings beyond 1 chain from standing timber, and seedbeds located there were exposed to more adverse environmental conditions.

Seedling Survival

Number of spruce seedlings 2 years old and older surviving in 1967 were related to quantity of 10-year seedfall into the clearcut opening, seedbed type, and environmental conditions.

Seedlings survived in significant numbers only on scarified seedbeds. Furthermore, seedlings were largely confined to the margins of the openings (fig. 6). The largest number of seedlings was established within 1 chain of the windward timber edge where nearly half of the seed dispersed fell. Those seedbeds were also protected from the prevailing winds and shaded part of the time by the trees along the windward timber margin, which created an environment more favorable to germination and establishment than elsewhere in the openings.

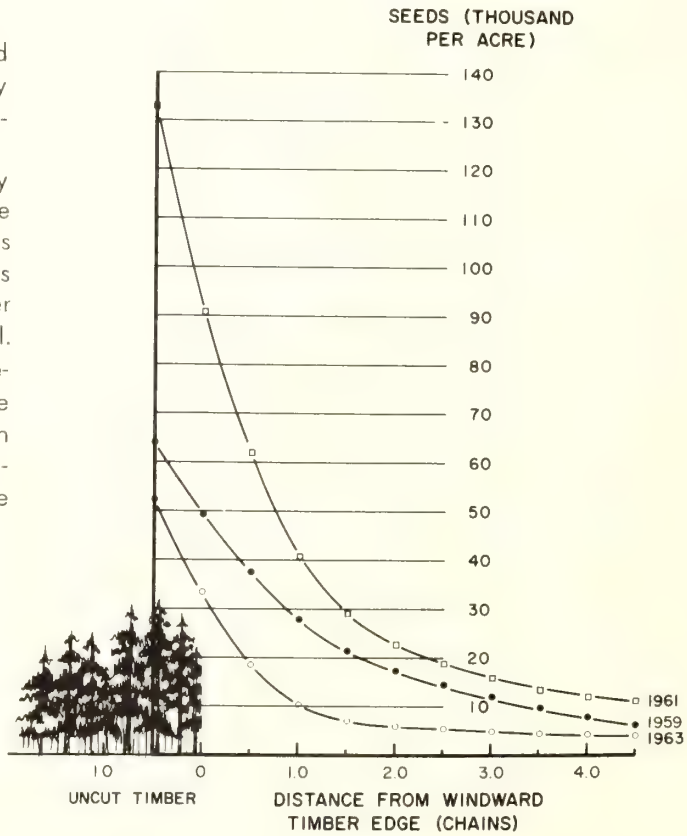

Figure 5.--Estimated Engelmann spruce seedfall from windward timber edge to 4.5 chains into the opening for years of significant seed protection.

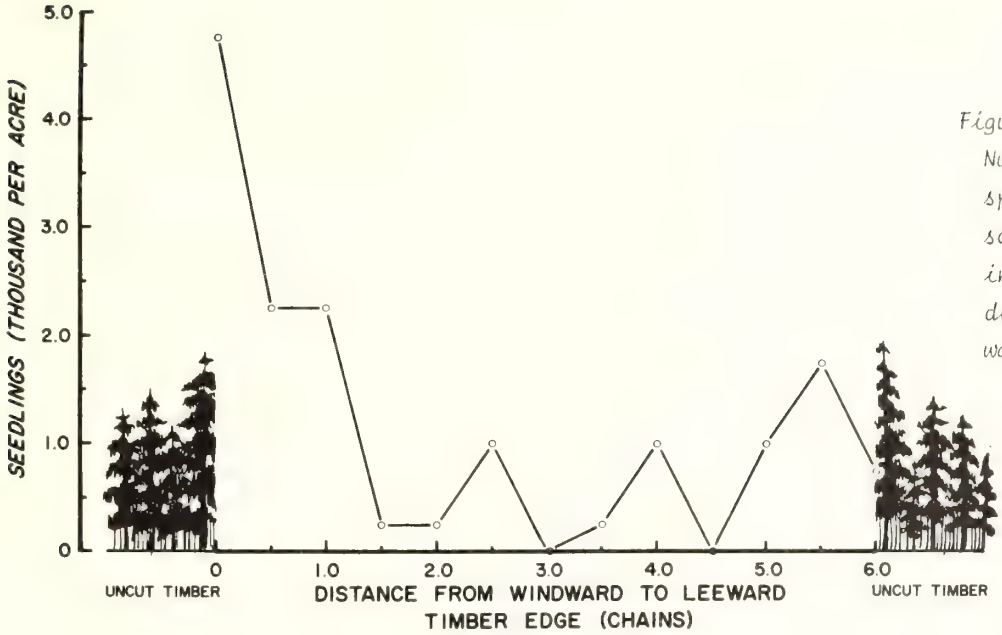

Figure 6.-- *Number of Engelmann spruce seedlings on scarified seedbeds in relation to distance from windward timber edge.*

The number of stocked milacres on scarified seedbeds was greater near the seed source where seedlings were more abundant. Fifty percent or more of the milacre plots within 1 chain of standing timber were stocked with from two to six seedlings. Beyond 1 chain from the timber edge, only two zones were more than 25 percent stocked, and none of the stocked milacres in those zones contained more than one seedling.

Seedlings did not become established on undisturbed seedbeds; only three out of 52 plots were stocked after 10 years, and each contained only one seedling.

Few spruces 2 years old and older became established on scarified seedbeds until 1961, when a large number of new seedlings from the 1959 seedfall survived the second growing season (fig. 7).[10] Many of those seedlings were not alive, however, at the end of the next growing season. There were small increases in seedling numbers in 1963 and 1964 from seed cast in 1961, but losses incurred in 1962 were not recovered. Seeds cast in 1963 produced few second-year seedlings, and the number of surviving seedlings gradually decreased after 1964, although seedling density was the same on all plots in the last 2 years of the study.

Large numbers of seed cast in 1961 and in 1963 were observed to germinate on scarified seedbeds, but most did not survive the first growing season. Although no weather records are available from the study areas, the survival data suggest that climatic conditions after the 1959 seedfall were more favorable to establishment than after seedfall in either 1961 or 1963. Furthermore, seedbed conditions on scarified plots were not as favorable to regeneration success after the 1961 and 1963 seedfall because of the increased competition from herbaceous vegetation.

Stocking to spruce was related to seedling density the first few years of observation, but stocking in 1967 was about the same as in 1961. The yearly variation in seedling density after 1961 generally resulted in changes in the number of seedlings per stocked milacre, but not in the number of stocked milacres.

[10] *The number of seedlings by years in figure 7 is for the scarified plots at the windward timber edge. Those plots were chosen to illustrate yearly variation because of the large number of seedlings, but the trend was the same on other scarified plots where seedlings became established in significant numbers*

Conclusions

Seed crops did not occur on Fool Creek with the same frequency observed elsewhere. Only

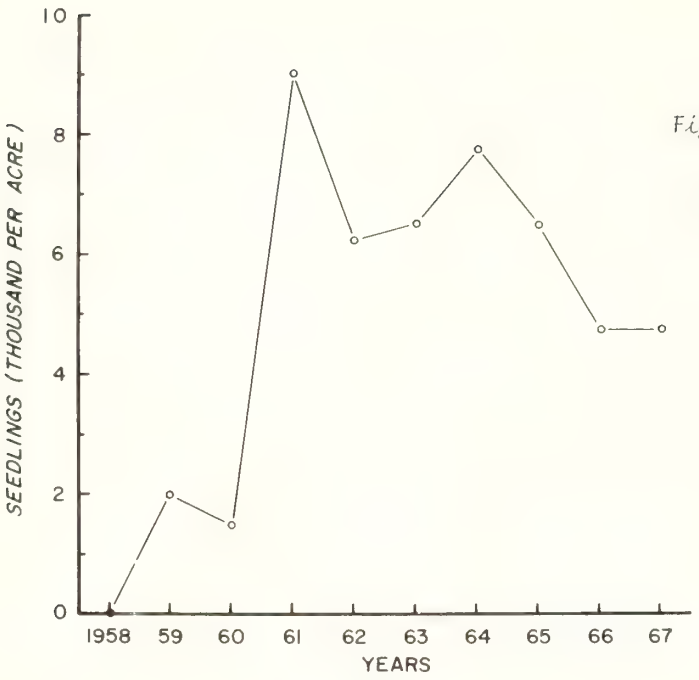

Figure 7.--Number of Engelmann spruce seedlings on scarified seedbeds at the windward timber edge in relation to years.

one good crop was produced in 10 years, and even moderate crops occurred at 4-year intervals. Seed production in other years was so low that for practical purposes it can be ignored. Infrequent seed crops means that natural reproduction cannot be expected every year.

Although most seed fell within 1.5 chains of the standing timber, sound seeds in considerable quantities were dispersed across the 6-chain-wide openings in years of moderate to good seed production. The pattern of seedfall was similar in those years, except for the quantitative differences largely associated with differences in the amount of seed produced and in wind movement across the clearings at the time seed was shed. Similar seed dispersal has been observed elsewhere in Colorado. That suggests that the pattern of spruce seedfall into clearcut openings in the central Rocky Mountains is influenced by the direction of prevailing winds as well as distance from source.

An ample seed supply is of little value, however, when seedbed or environmental conditions limit regeneration success. Seed in significant quantities and favorable seedbed conditions did not result in satisfactory restocking in the openings beyond the margins of standing timber; virtually no reproduction became established on unprepared seedbeds, even along the margins of openings where seed was available in considerable quantities and environmental conditions appeared to be favorable.

Scarification, aimed at increasing the suitability of the seedbed for seedling establishment by reducing competition, was not as effective as expected. Overall, however, scarification increased both stocking and numbers of seedlings, even though most of the seedlings were confined to the margins of the openings—where other environmental conditions also favored regeneration success.

No recommendations can be made concerning the size of opening that will restock to natural reproduction, or the cultural practices and protective measures needed to encourage seedling establishment. This study suggests however, that (1) seed supply is not the factor limiting regeneration success in small openings; (2) some form of seedbed preparation—at least the removal of heavy accumulations of duff and litter—is needed to encourage seedling establishment, and (3) if new seedlings are to survive, they must be protected from adverse environmental factors such as intense solar radiation and high temperatures, low temperatures and frost heaving, and drying winds.

Considerably more information is needed on germination and survival under different combinations of seedbed and environment to provide estimates of the probability of seedling establishment. Additional data are also needed on the amount of seed produced, periodicity of seed crops, and dispersal distances to work out relationships between seed supply and size of opening. Once estimates of seed supply and the number of seeds required to provide an established seedling are available, the size of opening that will restock to natural reproduction can be determined for a variety of conditions.

Agriculture --- CSU, Ft. Collins

Alexander, Robert R.
1969. Seedfall and establishment of Engelmann spruce in clearcut openings: A case history. USDA Forest Service Research Paper RM-53, 8 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

Spruce seedfall and the establishment of new seedlings were observed on two 3.5-acre clearcut openings on the Fraser Experimental Forest, Colorado, 1956-65. Only one good and two moderate seed crops occurred during that period. Numbers of sound seed caught in traps placed beneath the uncut stands along the margins of the openings were always greater on the windward side of the openings. Seed dispersal into the openings was not uniform but decreased in an exponential manner from the windward source to about two-thirds of the distance across the openings. Although nearly one-half of the total number of seeds caught in traps placed across the openings fell within 1.5 chains of the windward timber edge, nearly 10 percent fell as far out as 4.5 chains. However, seedlings became established in significant numbers only on scarified seedbeds along the margins of the openings.

Key words: Silviculture, forest seed production, seed dissemination, tree seedlings

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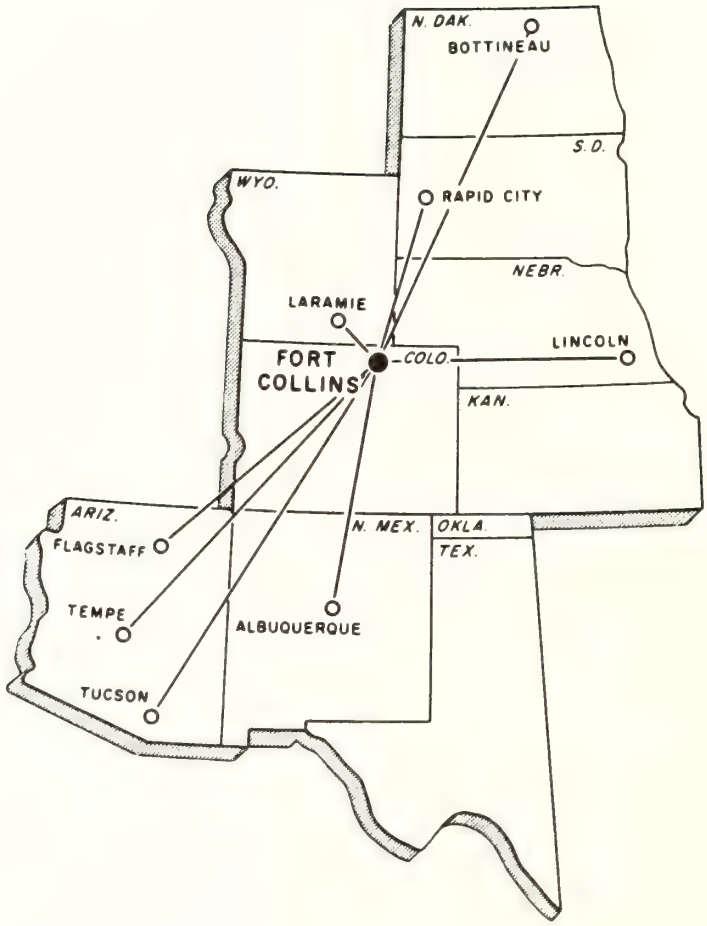
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ROOT COMPETITION

BETWEEN PONDEROSA PINE SEEDLINGS AND GRASS

M.M. LARSON
GILBERT H. SCHUBERT

USDA FOREST SERVICE
Research Paper RM - 54

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
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Root Competition Between Ponderosa Pine Seedlings and Grass

by

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and

Gilbert H. Schubert, Principal Silviculturist

Rocky Mountain Forest and Range Experiment Station[1]

[1]Central headquarters maintained at Fort Collins, in cooperation with Colorado State University; authors are located at Flagstaff, in cooperation with Northern Arizona University. Larson is now with the Forestry Department, Ohio Agricultural Research and Development Center, Wooster, Ohio.

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Root Competition Between Ponderosa Pine Seedlings and Grass

M. M. Larson and Gilbert H. Schubert

Introduction

Grass is a common ground cover throughout the ponderosa pine (*Pinus ponderosa* Laws.) forests of the Southwest. Although a valuable forage resource, its presence is definitely detrimental to initial establishment of coniferous reproduction. Certain grasses, however, seem to compete less intensely than others with pine seedlings. This difference in competitiveness is exemplified by two native bunchgrasses: Arizona fescue (*Festuca arizonica* Vasey), a strong competitor, and mountain muhly (*Muhlenbergia montana* (Nutt.) Hitchc.), a mild competitor (Pearson 1942). This Paper reports on investigations of the tree-grass relationship on the Fort Valley Experimental Forest near Flagstaff, Arizona.

Materials and Methods

The study was conducted in two environments: glass-faced planter boxes set in the ground at the Fort Valley nursery, and field plots in a nearby old clearcut opening in a ponderosa pine stand. Both locations were at an elevation of about 7,400 feet.

Glass-Faced Planter Boxes

Dormant ponderosa pine, Arizona fescue, and mountain muhly seedlings were planted on April 12, 1963, in nine glass-faced boxes previously described by Larson (1962) and Lavin (1961) to study root development. These boxes, 2 feet by 3 inches at the top and 2 feet deep, were slid into wooden frames that had been buried in the ground at a 30° angle from vertical. The side of the box with the removable glass face was placed downward and the top level with the soil surface.

Moist, gravelly, clay loam soil, derived from basalt, was dug from a nearby pit and transferred to the boxes at approximately the same original horizons. Adequate drainage was provided through a layer of coarse volcanic cinders and holes drilled in the bottom of the boxes. After each box was filled with soil it was lifted from the wooden frame, placed flat on the ground, and the glass plate removed.

Seedlings were then placed on the exposed soil at regular planting depth with roots extended. Two 2-0 ponderosa pines from the adjacent nursery beds were planted 1 foot apart in each of the nine boxes. Arizona fescue and mountain muhly plants from a nearby natural grass stand were separated into very small individual entities, root pruned to 4 inches, and then planted in six of the boxes, three for each of the two grass species. Three grass transplants were planted on each side of the pine. The glass was then replaced carefully to avoid disturbing the roots and the box inserted into the frame.

The plants were watered immediately after planting and at weekly intervals during the spring and fall drought periods. Each watering was equivalent to 0.5 inch of rain.

Roots were measured twice weekly during the spring of the first growing season. The interval between subsequent measurements was adjusted according to the amount of new root growth. Heights were measured several times during the growing season.

Final measurements were made at the end of two full growing seasons. After the depth of the pine root system was measured, the pine and grass seedlings were carefully washed from the soil. New root tips on the pines were counted, then all plants were photographed, dried, and weighed.

Field Plots

Two-year-old ponderosa pine seedlings were planted April 25-28, 1964, in six replications each containing six plots — two each of Arizona fescue, mountain muhly, and denuded cover types. Nine pine seedlings, of Arizona seed origin grown at the Bend Nursery in Oregon, were planted at a 1-foot spacing in each of the 3-foot-square plots.

The natural grass stand in the study area consisted almost entirely of the two bunchgrass species arranged as a mosaic of single species clumps up to 6 feet in diameter. Plots were located in the centers of the grass clumps and denuded spots. All six plots of each replication were within a 25-foot-square area.

Figure 1.--Mountain muhly cover type plot planted with nine 2-0 ponderosa pine seedlings, one to each square foot. The black border is the upper edge of the plastic root barrier. White tags indicate the location of some pine seedlings.

Table 1.--Average growth per planter box of fescue and muhly grasses after two growing seasons

Grass species	Dry weight			Root/shoot ratio	Leaf height
	Roots[1]	Tops	Total		
	- - - Grams - - -				Inches
Fescue	106.0	[2]49.3a	148.7c	2.15d	10.3f
Muhly	76.0	73.2b	149.2c	1.04e	14.3g

[1]Root dry weight of the two grasses significantly different at the 10 percent level.
[2]Any two means in each column not followed by a similar letter are significantly different at the 5 percent level.

Table 2.--Average growth per plant of ponderosa pine seedlings grown in three cover types in planter boxes

Cover type	Dry weight			Root growth	
	Roots	Tops	Net gain[1]	Active laterals[2]	Longest root[3]
	- - - Grams - - -			Number	Inches
Fescue	[4]0.57a	0.90c	0.24e	1.2g	20.8i
Muhly	.96a	1.22c	.80e	3.2g	22.8ij
Grass-free	3.37b	4.75d	6.76f	13.2h	27.5j

[1]Net gain = dry weight (roots + tops) when harvested minus dry weight (estimated from green weight) when planted.
[2]First- and second-order lateral roots with white tips were considered "active."
[3]Measured from root crown to tip of longest lateral root.
[4]Any two means in each vertical column not followed by a similar letter are significantly different at the 5 percent level.

Results of Field Tests

Watered pine seedlings survived better than unwatered seedlings the first growing season. Mortality of watered pines averaged 32 percent, with no significant differences among the three cover types (fig. 7). Mortality of unwatered pines averaged about 72 percent, with significant differences among cover types.

Mortality of watered seedlings was highest during the first winter after planting, whereas mortality of unwatered seedlings was highest during the spring drought soon after planting.

Poor vigor of the pine seedlings was evident during the first growing season. By July 14, only 6 of the 36 excavated seedlings had new root growth. Furthermore, many of the pines had western gall rust.

Only 57 pines survived the two growing seasons. In general, unwatered pines in the denuded plots grew better than those in a grass cover (table 3). However, unwatered pines in muhly tended to grow better than those in fescue. Watered pines grew equally well in all cover types, but significantly less than those in unwatered bare plots.

Pine seedlings grew less than 2 inches in height during the two growing seasons. Watered fescue and muhly plants averaged 18 inches in height compared to 15 inches for unwatered.

Roots, at end of second growing season, washed from a glass-faced planter box:

Figure 4.--
Left, ponderosa pine and Arizona fescue;

Right, pine removed from fescue.

Figure 5.--
Left, ponderosa pine and mountain muhly;

Right, pine removed from muhly.

Figure 6.--Ponderosa pine, grown without competing grass.

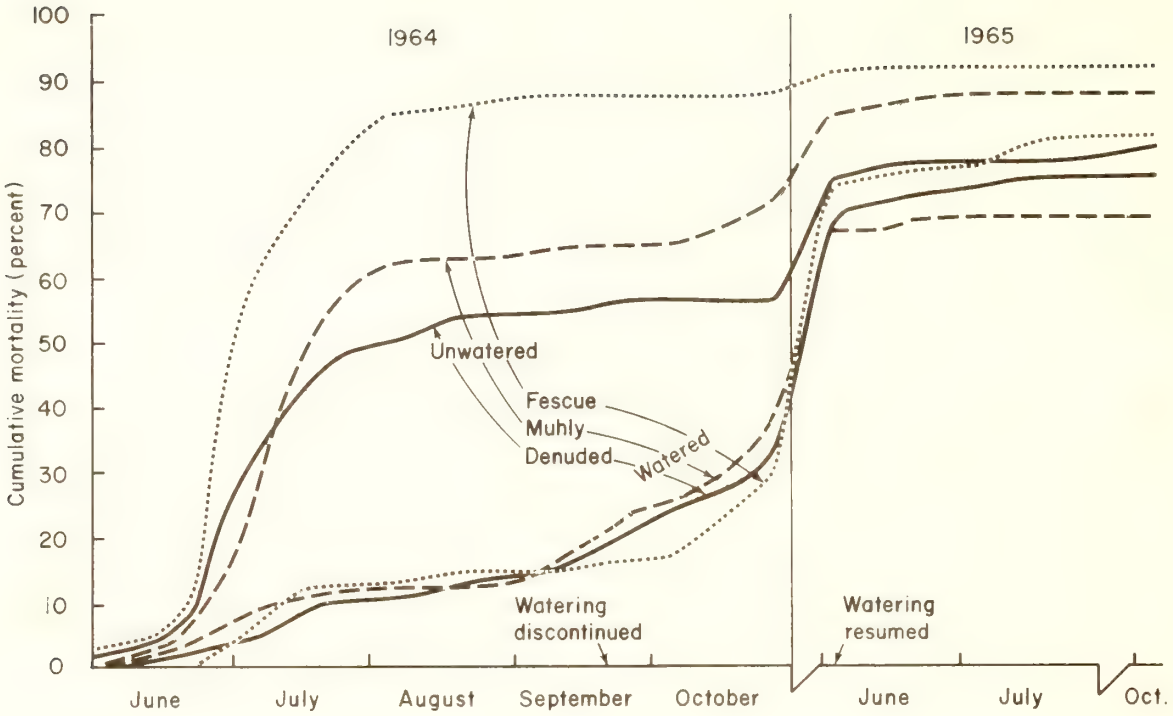

Figure 7.--Cumulative mortality of ponderosa pine seedlings planted in field plots containing Arizona fescue and mountain muhly, 1964 (last count on October 27) and 1965 (last count on October 4).

Table 3.--Average growth of unwatered ponderosa pine seedlings after two growing seasons, by cover type

Cover type	Dry weight		Root growth		
	Roots	Tops	Lateral root length[1]	Deepest root	Active root tips[2]
	- - Grams - -		- - Inches - -		Number
Fescue	[3]0.95a	1.10a	8.90a	18.45a	0.69a
Muhly	1.79b	2.76ab	10.70a	20.81a	2.19a
Denuded	3.73c	6.98b	21.40b	29.09b	6.92b

[1]Determined by averaging the four longest lateral roots of each seedling.
[2]All roots that had light-colored root tips were counted as "active."
[3]Any two means in each vertical column not followed by a similar letter are significantly different at the 5 percent level.

Soil moisture depletion was least on the denuded and greatest on the fescue plots (figs. 8, 9). Soil moistures were significantly different in early July and October in 1964 and in July and September in 1965. Fescue reduced the moisture potential of soil at the 4-inch depth to or below -15 bars twice during both years, whereas muhly reduced the moisture to this extent only once each year. Soil moisture below 16 inches was continuously adequate for plant growth both years. Soil moisture at the 4-inch depth in watered plots was maintained between 20 to 27 percent.

Thermistors installed in the moisture blocks performed too poorly to warrant a detailed presentation of the results. However, a few did provide consistent readings that indicated temperature trends. Soil temperatures at the 16- and 24-inch depths increased from the low 40° F. in early May to about 70° F. in mid-August. Noon soil temperatures at 4-inch depths exceeded 75° F. only in the denuded unwatered plots. These temperatures averaged about 2° to 4° F. higher than those at the same depth in unwatered grass-covered plots and up to 16° F. higher than those in watered denuded plots during the warm, dry periods. Soil temperatures in the watered grass plots averaged 3° to 5°F. cooler than those for unwatered plots. During the rainy season, soil temperatures at the 4-inch depth were similar for all plots.

Average weekly air temperatures at 3 inches above the ground did not exceed 68° F. during the two growing seasons

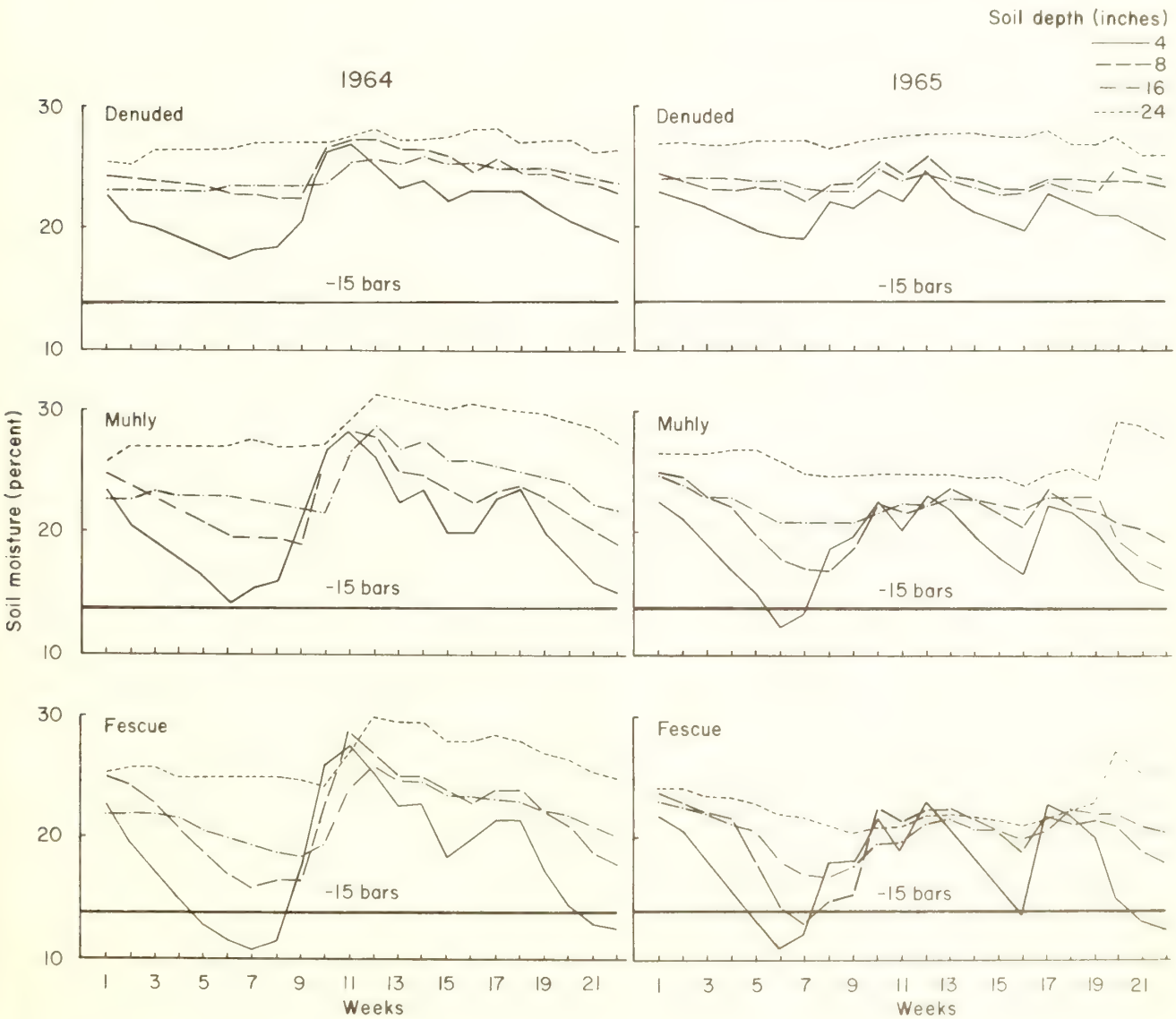

Figure 8.--1964.

Figure 9.--1965.

Soil moisture (weight of water/weight of dry soil in percent) at indicated depths for each unwatered cover type June-October. Moisture content of surface soil at a matric potential of -15 bars is shown.

(fig. 10). Average weekly minimum temperatures were usually under 50° F. with temperatures dropping to or below 32° F. every month. Maximum air temperatures never exceeded 100° F.

About 11 inches of rain fell on the study area each year during the period June 1 to September 30. Relative humidities ranged from 15 to 30 percent at noon during the drought periods, and 40 to 50 percent during the late July-August wet periods.

Needle moisture content (NMC) of the pines averaged 165 percent at time of planting. On June 3, the average NMC of the needles dropped to 140 percent, with no significant treatment differences (table 4). By July 11, near the end of the spring drought, the NMC of live seedlings averaged only 108 percent. At this time the average NMC of watered seedlings was significantly higher than that of unwatered seedlings in each cover type. Furthermore, the NMC of unwatered seedlings was significantly higher for pines in the denuded plots than in the two grass-covered plots. By August 31 (after several rains) the average NMC of live seedlings was up to 128 percent.

Trends in water saturation deficits (WSD) of seedlings were similar to those of NMC (table 4). Values for WSD and NMC are inversely related to each other. The WSD was 8 percent (near full saturation) at time of planting, 35 percent on July 11 (symptoms of wilting observed) and 28 percent on August 31. Both WSD and NMC were more favorable for survival of unwatered pines than of watered pines on August 31. The water balance of needles (WSD and NMC) was similar for the two collection times — just before sunrise and 10 hours after sunrise.

The NMC and WSD measurements on June 3 were related to the seedlings' ability to survive the ensuing drought period

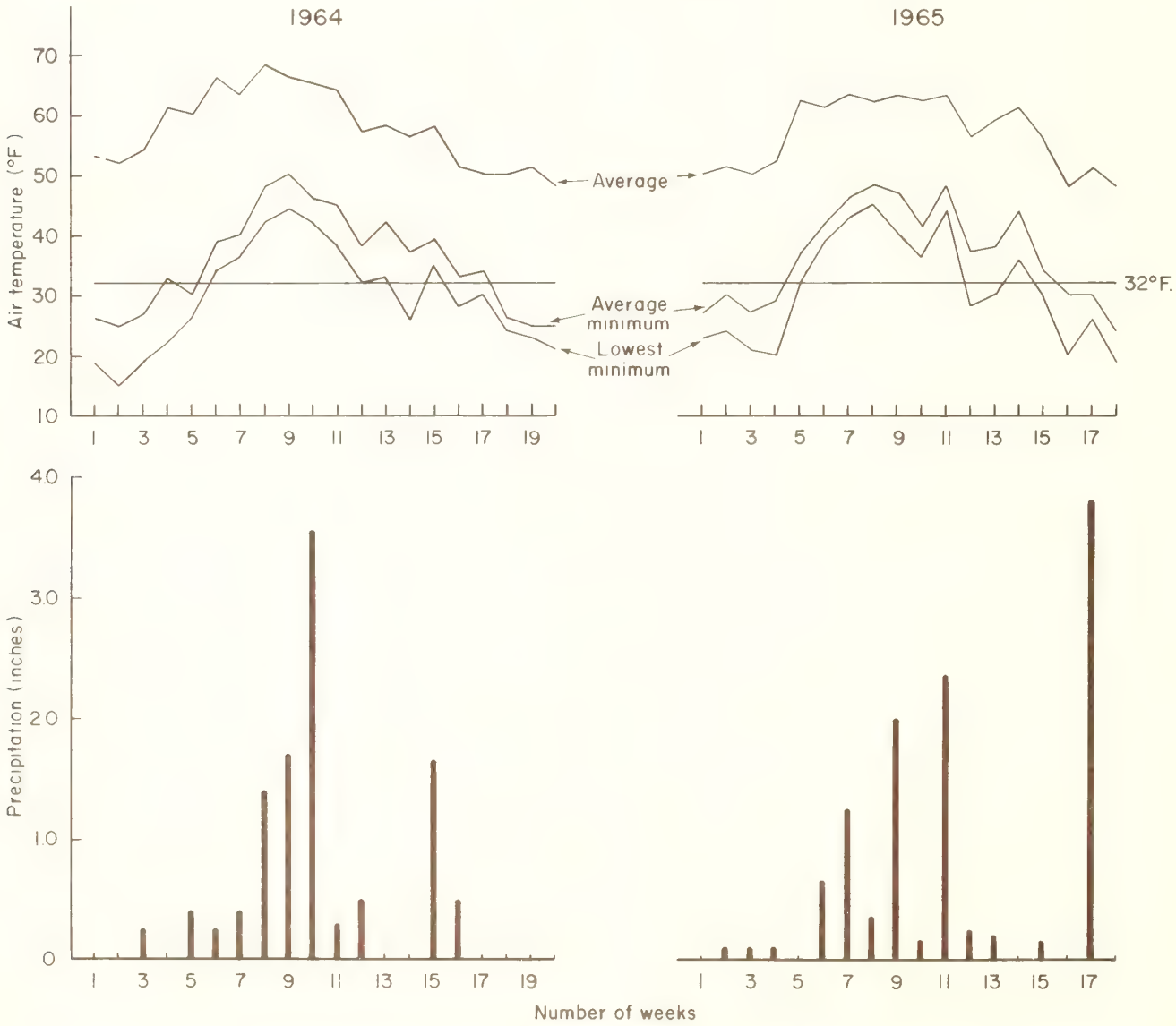

Figure 10.--Air temperatures at 5 inches above ground level (weekly average, weekly average minimum, and lowest minimum recorded each week) and total weekly precipitation during two growing seasons 1964 (June-October) and 1965 (June-September).

Table 4.--Averages of needle moisture content (NMC) and water saturation deficit (WSD) of ponderosa pine seedlings at three dates during the first growing season after planting. (Needles collected 10 hours after sunrise on clear days)

Cover type	Moisture treatment	June 3		July 11		August 31	
		NMC	WSD	NMC	WSD	NMC	WSD
		- - - - - - Percent - - - - - -					
Fescue	Watered	143	27	114	37	129	27
	Unwatered	138	30	85	46	142	22
Muhly	Watered	141	27	132	27	126	28
	Unwatered	140	28	84	44	135	21
Denuded	Watered	140	28	128	28	124	25
	Unwatered	137	28	106	29	130	19
Average		140	28	108	35	128	25

(figs. 11, 12). The probability of survival of watered seedlings remained favorable (0.70) even when the June 3 NMC was low (110 percent) or the WSD was high (50 percent). In contrast, the probability of survival of unwatered pine seedlings was less than 50 percent when the NMC was below 146 percent or the WSD was above 25 percent.

Discussion and Conclusions

The investigation of the nature and effect of competition between ponderosa pine seedlings and grass has provided data on growth comparisons and reasons why pines survive and grow better in grass-free environments.

Ponderosa pine seedlings grew best on well-prepared plots. Root and top growth were both significantly greater when pines were grown without competition from grass. The pine seedlings on denuded plots showed an elevenfold greater net gain in dry weight than those grown in competition with grass. Dry weights of roots and tops of pines grown on bare soil were over four times more than for pines grown in grass.

Mountain muhly, a warm-season grower, retarded growth of ponderosa pine seedlings less than did Arizona fescue, a cool-season grower. Net gain in dry weight of pines growing with muhly was nearly four times that of pines growing with fescue.

Grass roots grew faster than pine roots. Main roots of muhly and fescue elongated at a rate 50 percent greater and thereby occupied a given volume of soil sooner than pine roots. At the end of 2 years, dry weight of grass roots was 11 to 16 times greater than the weight of the tree roots for seedlings grown in planter boxes. However, the root weight of the grasses in the boxes was three to four times greater than the root weights reported for a similar volume of soil in an ungrazed mountain muhly pasture in Colorado (Schuster 1964).

Arizona fescue and mountain muhly were more drought tolerant than ponderosa pine seedlings. Grass, in the field plots, recovered original greenness and grew vigorously following the late spring-early summer drought when the soil moisture was replenished by July and August rains. In contrast, about half of the newly planted pines in the field plots died during the drought period unless watered. Roots of both pine and grasses became dormant as the soil dried out in the planter boxes. When the soil was rewetted and kept moist, the grasses produced many new laterals and a flush of new main roots within 2 to 3 weeks, whereas pines produced only a few new roots after rewetting.

A faster recovery of brome grass over hardwood seedlings during droughts was also reported by Lane and McComb (1948). Richardson (1953) observed that grasses reduced the period of active root growth of Acer seedlings, and noted that grass suppressed lateral root growth more than the main root of tree seedlings. In our study, laterals grew more on pine seedlings grown without grass than in boxes with grass.

Arizona fescue and mountain muhly depleted soil moisture faster and to lower levels than ponderosa pines. Similar results were reported by Pearson (1950) in soil moisture trends in natural grass and denuded areas. Arizona fescue depleted the soil moisture more than mountain muhly, and reduced it to critical levels for plant growth during both the spring and fall droughts. Conard and Youngman (1965) found that cold-season pastures suffered more often from midsummer drought than warm-season pastures. Barrett and Youngberg (1965) reported a 45 percent greater use of water in a sapling stand of ponderosa pine with an understory than in one without an understory.

Arizona fescue completed its height growth by about mid-June compared to late summer for mountain muhly. Jameson (1965) found similar times for final height growth of other warm- and cold-season grasses in northern Arizona. In our study both grasses formed new short leaves in the fall that were carried through the winter.

Pine seedlings had a lateral root system advantage over the grasses. Some first-year laterals on the pines exceeded 30 inches in the field experiments. Schuster (1964) reported that the root spread for fescue and muhly averaged only about 1 foot in ungrazed pastures. This widespread root system of pines

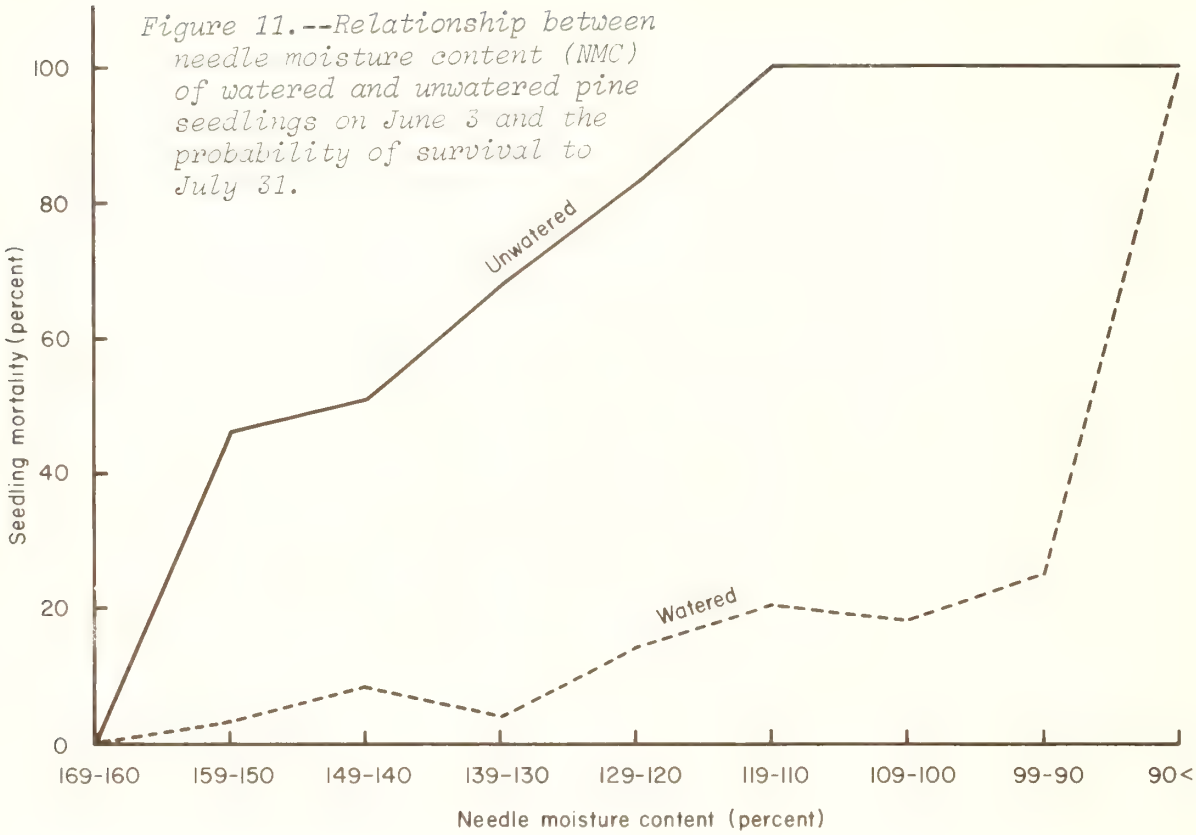

Figure 11.--Relationship between needle moisture content (NMC) of watered and unwatered pine seedlings on June 3 and the probability of survival to July 31.

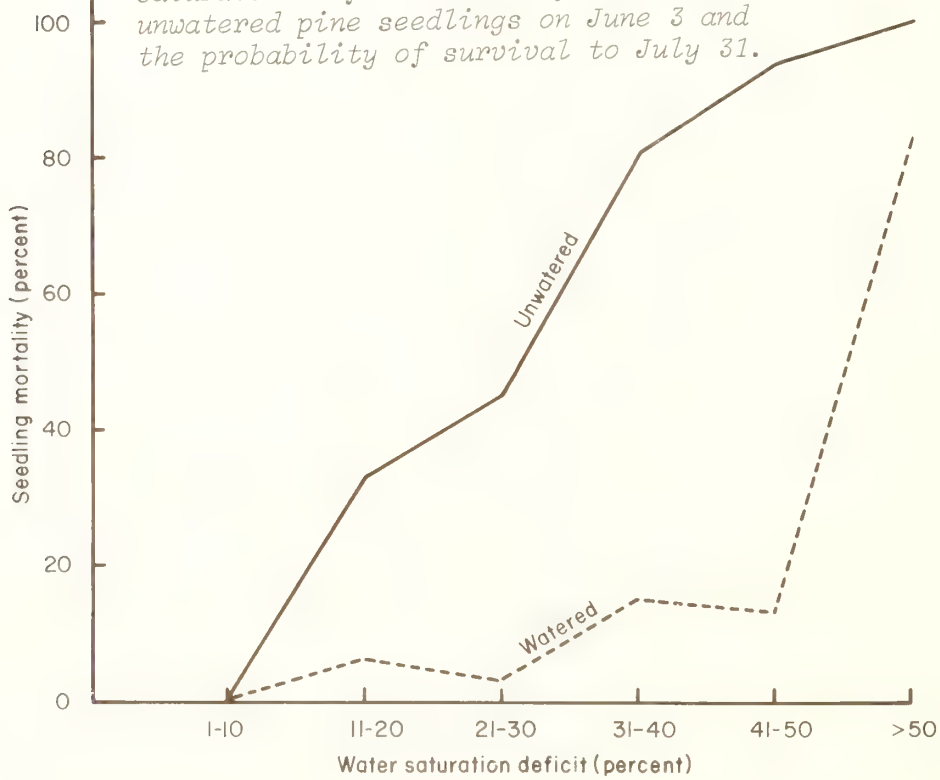

Figure 12.--Relationship between the water saturation deficit (WSD) of watered and unwatered pine seedlings on June 3 and the probability of survival to July 31.

is better than the compact root system of grasses because it provides a larger area to tap soil moisture.

Soil moisture remained high below the 16-inch depth for all cover types, with few grass roots below this depth. Similar results were obtained by Schuster (1964) and by Cohen and Strickling (1968). Main roots of all surviving pines extended below the 16-inch depth.

Established pines can tolerate some competition for moisture by grasses. Only 9 percent of the pines that survived the first drought period died during the second growing season. In California, Baron (1962) found that ponderosa pines were able to compete with grasses if the pines were planted before or at the same time the area was seeded with grass. However, pines sustained heavy mortality on areas planted a year or more after the grass seeding. In Arizona, pines from the successful 1919 seedling crop gained dominance over the grasses within 5 years (Arnold 1950). Pearson (1942) reported that pines from the 1919 seedling crop survived in great numbers in competition with muhly but not with fescue.

Pine seedlings grew best in unwatered bare plots. The relatively poor growth of watered seedlings may have been due to excessive water at the lower soil depths. Soil moisture at the 4-inch depth usually remained below field capacity, but moisture at lower depths was not measured in watered plots. Also, the midday soil temperatures of unwatered plots were often considerably higher and more favorable for seedling growth than were the temperatures of watered plots.

There was no evidence that grass roots produced growth inhibitors that suppressed the elongation of pine roots. Pine roots elongated as rapidly in boxes with grass as those without grass as long as soil moisture was adequate (fig. 2). Also, pine seedling survival the first season in the watered field plots was similar for all cover types. The grasses may have produced growth inhibitors when soil moisture stress was high, but the two effects cannot be separated in these data.

Height growth of pine seedlings was a poor indicator of competition. Frequently, ponderosa pines make very little top growth the first year or two after outplanting. Most of the growth during these years is on the root system. Richardson (1953) concluded that height increment was an unsatisfactory basis for comparative growth studies of young trees. Sutton (1967) found that first-year height increment of outplanted spruce seedlings was similar for several levels of root pruning.

Water balance of pine seedlings varied both with season and treatment. The needle moisture content (NMC) and water saturation deficits (WSD) data indicated that the internal moisture stress of needles was low at time of planting and very high during early summer drought. During this drought period, pine seedlings in unwatered plots containing fescue and muhly developed greater internal moisture stresses than pines in denuded or watered plots. After 2 months of summer rains, however, the water balance of unwatered pines was better than that of the watered pines (table 4). This late summer difference in water balance may not be significant, however. The NMC and WSD data recorded on August 31 included statistics for poor-quality watered pines that later died during the fall and winter months (fig. 7). The poor-quality unwatered pines were not included since they had already died during the June drought.

Water saturation deficit (WSD) of pine seedlings on June 3 was a better indicator of survival potential than NMC (figs. 11, 12). Seedlings with WSD values above 25 percent on June 3 had less than a 50-50 chance to survive the June drought. Oppenheimer and Shomer-Ilan (1963) observed internal cellular damage in needles of *Pinus pinea* and *P. halepensis* that reached a WSD of 25 percent.

Pine needles displayed various visual symptoms of drought damage. These symptoms were related to NMC as follows: needles green, 150 percent; needles light green, 111 percent; tips of needles brown, 107 percent; needles with purplish cast, 101 percent; needles with necrotic yellow spots, 84 percent; and needles yellow, 55 percent. The coefficients of variation ranged from 5 percent for seedlings with yellow needles to 17 percent for seedlings with light green needles. A needle moisture content (NMC) (based on ovendry weight) less than 110 percent combined with a WSD greater than 45 percent appears to be the "point of no return" for ponderosa pine seedling survival. Ursic (1961) concluded that an NMC of about 80 percent identified the death point of loblolly pine (*Pinus taeda L.*) seedlings.

Needles subjected to severe drought may not fully recover their former turgidity after the drought is broken. Freshly cut needle fascicles were saturated and subjected to simulated drought conditions by drying until various water saturation deficits (WSD) up to 42.2 percent were reached. The needles were then resaturated and reweighed. Differences in water content between first and second saturations became progressively larger as the WSD increased.

Recommendations

Results of this study show that ponderosa pine should be planted only on grass-free areas. Therefore, if grass is present, it must be killed or removed before trees are planted. Furthermore, since water is in short supply and pine roots reach out several feet, complete site preparation provides the best condition for tree survival and growth. Partial site preparation has been inadequate and is not recommended for the Southwest.

Grass can be effectively killed with dalapon during the summer or removed with a bulldozer in the fall before planting. Current research will determine if grass can be effectively killed with other herbicides at time of planting. Until new research provides other alternatives, dalapon or bulldozer treatment at the recommended times are the best methods to prepare planting areas.

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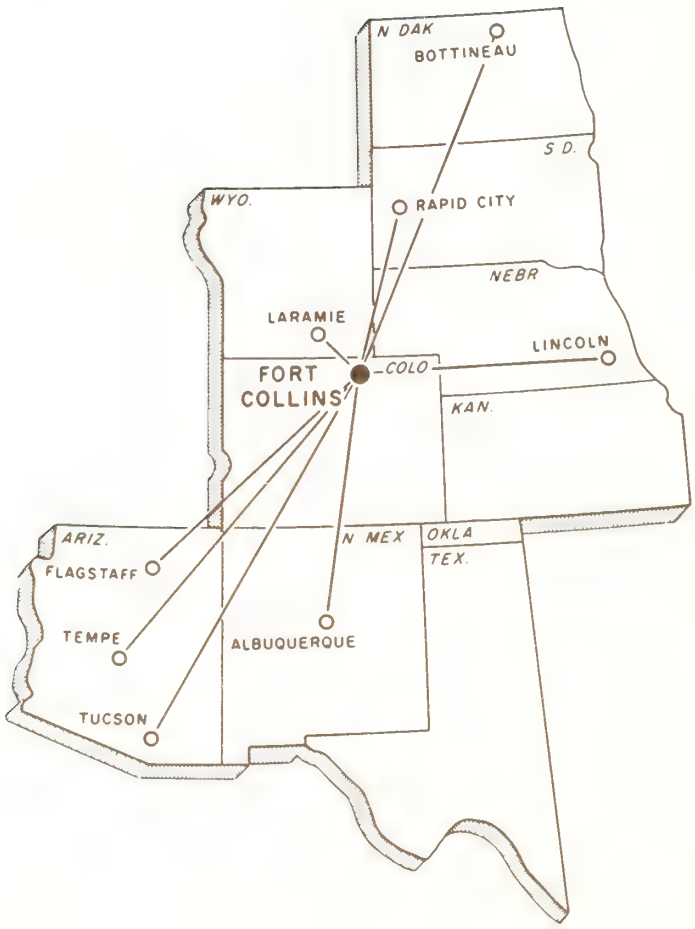
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by
H. W. SPRINGFIELD

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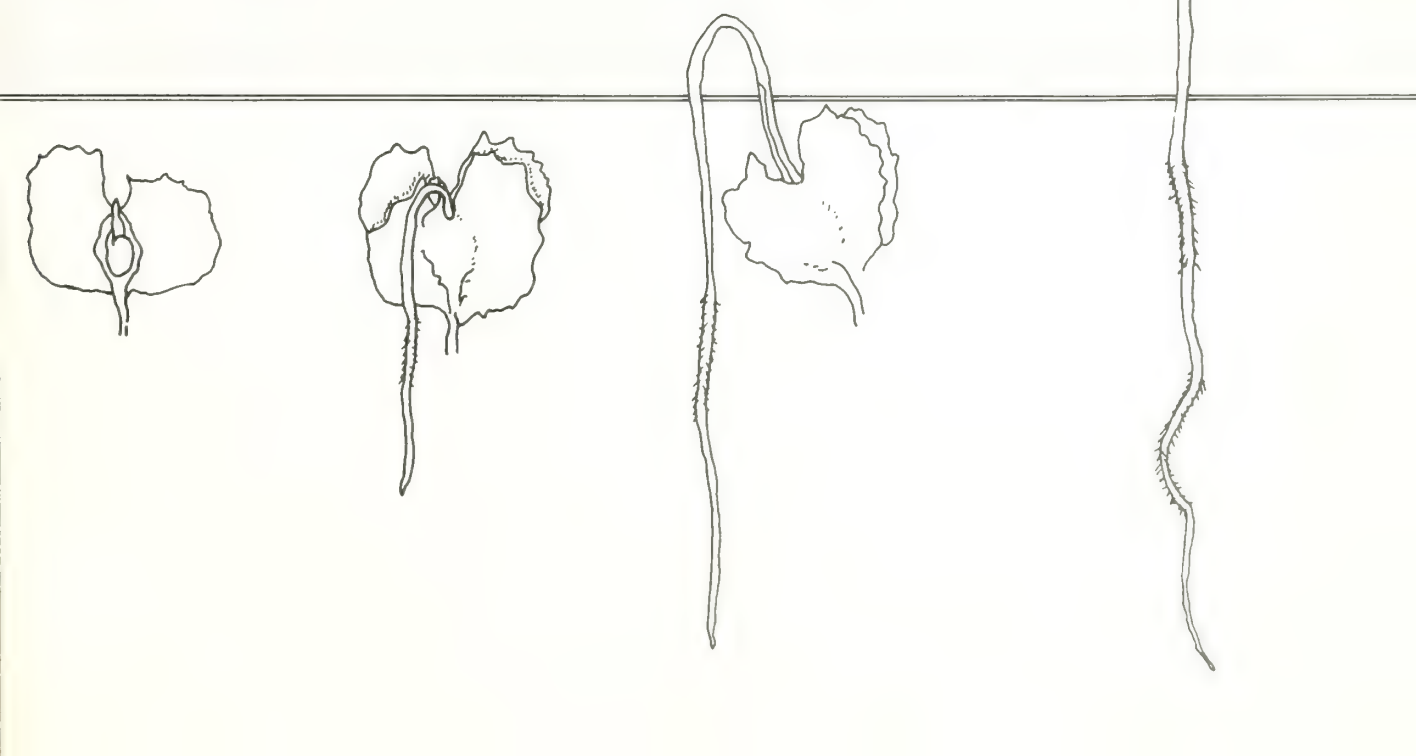

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1970

Germination and Establishment of Fourwing Saltbush in the Southwest

by

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Rocky Mountain Forest and Range Experiment Station[1]

[1]Central headquarters maintained at Fort Collins, in cooperation with Colorado State University; author is located at Albuquerque, in cooperation with the University of New Mexico.

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Germination and Establishment of Fourwing Saltbush in the Southwest

H. W. Springfield

PURPOSE OF THE STUDY

Fourwing saltbush (Atriplex canescens (Pursh) Nutt.)[2] is one of the most important shrubs on western ranges. Widely distributed, this plant furnishes forage for livestock and wildlife in all seasons; it is especially valuable as browse on winter ranges. Also known as chamiza in the Southwest, and as buckwheat shrub, white greasewood, saltsage, bushy atriplex, and wafer sagebrush elsewhere, fourwing saltbush derives its most common name from the characteristic four-winged fruit. Its importance is due to abundance, accessibility, size, large volume of forage, evergreen habit, high palatability, and nutritive value (U. S. Forest Service 1937). Nearly 70 years ago, Smith (1900) recommended this species for cultivation because of its high nutritive value and growth on poor and salty soils.

Through the years, fourwing saltbush has been seeded numerous times by ranchers and public agencies. Some seedings were successful, but many of them failed. Poor seedbed preparation, wrong time of seeding, and destruction by rabbits or rodents have been offered as explanations for the seeding failures. Recent investigations indicate many different factors influence the germination and establishment of fourwing saltbush. The results of a variety of experiments are summarized in this report. The information should be useful to anyone planning to revegetate ranges with fourwing saltbush.

DISTRIBUTION AND GENERAL CHARACTERISTICS

Fourwing saltbush grows from eastern Oregon to North Dakota and southward to Mexico, and is common in central and southern Nevada, Utah, Arizona, New Mexico, the Mojave and Colorado Deserts of California, western Texas, and northern Mexico. A. canescens is one of the most widely distributed species of Atriplex in the United States (Bidwell and Wooten 1925, Dayton 1931).

It is a common plant of dry, moderately saline sites in the plains, foothills, and intermountain valleys of the creosotebush, sagebrush, desert grassland, oak woodland, and pinyon-juniper types. Sometimes it is the dominant species over extensive areas, but more often it grows mixed with other shrubs, grasses, and forbs.

Plants grow naturally under a variety of soil and climatic conditions. It is found on sand dunes, alluvial flood plains, gravelly washes, mesas, ridges, and slopes. Usually it is most vigorous in sandy loam or loam soils, but plants will grow in clay soils. It tolerates salinity, but is not restricted to saline soils (U. S. Forest Service 1937). Wilson (1928) reported it does not grow naturally on noncalcareous soils.

Roots of mature plants will reach depths of 5 to 15 meters (m.) in alluvial soils. Its extensive root system makes the plant remarkably drought resistant (Van Dersal 1938).

Fourwing saltbush is medium sized, grayish white, and evergreen (fig. 1). Ordinarily, mature plants are 1 to 2 m. tall. Plants branch freely from the ground surface; the woody branches are rigid and rather brittle. Bark of the older branches is roughened by small longitudinal fissures and exfoliates. The leaves, pale grayish green, thick, glabrous, alternate, and often clustered, are mostly 2 to 5 cm. long and 2 to 7 mm. wide. Though the plant is classed as an evergreen, many leaves are dropped each year, especially during winter at the higher elevations. Staminate and pistillate flowers are on different plants. The nonshowy, small, greenish-yellow flowers form in panicles at the ends of young stems during summer. Characteristic four-

[2] *Common and botanical names of plants associated with fourwing saltbush are listed on page 48.*

Figure 1.--Vigorous, productive, fourwing saltbush near Isleta, New Mexico.

Male and female flowers usually are borne on separate plants. The "seed" or fruit (utricle), is one celled, one seeded, and fourwinged. A single large plant may yield as much as 10 pounds of seed.

winged fruits develop gradually through the summer, turn yellow, and ripen in the fall. The fruit is dispersed by wind and gravity. Seed-bearing age ordinarily is 2 to 4 years, but 1-year-old plants have produced seed (fig. 2).

One of the most palatable of southwestern shrubs, the leaves, stems, and fruits of fourwing saltbush are cropped by all classes of livestock. Horses and deer browse fourwing saltbush mainly during the winter (Judd 1962). Scaled quail utilize the plant for shade, cover, roosting, and food (Van Dersal 1938). Burnham and Johnson (1950) recommend it for quail cover in New Mexico. Its forage value is almost legendary; a large number of references testify to its nutritive quality and usefulness (Dayton 1931 , Bridges 1942, Benson and Darrow 1944, Cook et al. 1954). The plants are relatively high in crude protein, calcium, and phosphorus throughout the year, as shown by these analyses of samples from central New Mexico (Watkins 1943):

	Crude protein	Calcium	Phosphorus
	- - - (Percent) -	- -	
March	10.0	1.5	0.09
June	15.8	1.3	.20
September	13.5	1.4	.15
December	11.1	1.0	.12

Bidwell and Wooten (1925) reported protein contents of 14 to 18 percent for samples collected in midwinter. Cattle have been held exclusively on fourwing saltbush areas for 9.5 months to demonstrate its value as an emergency feed (Foster et al. 1921). Costello (1944) reported cattle gained more on pastures where there were fourwing saltbush plants. Saltbushes are classed as secondary selenium absorbers in that the plants will accumulate this element on selenium-bearing soils (Schmutz et al. 1968).

Figure 2.--This plant established at Santa Fe, New Mexico, by direct seeding in August 1967 produced seed in September 1968.

METHODS OF STUDY

Seed germination and seedling characteristics were studied mainly in a laboratory and nursery at Santa Fe, New Mexico.[3] Methods of establishment and adaptability were studied at several representative sites (table 1).[4]

[3]*These studies were conducted in cooperation with the New Mexico Department of Game and Fish under the Federal Aid to Wildlife Restoration Act, Pittman-Robertson Research Project W-109-R-3, "Range Revegetation Investigations."*

[4]*Field studies were made mostly on National Forests in cooperation with the Southwestern Region of the U. S. Forest Service, Albuquerque, New Mexico.*

Seed germination studies were conducted in a standard Da-Lite (Stults Scientific) germinator[5] equipped to control temperature (55° to 90° [6]) and light, a Mangelsdorf germinator with temperature (70° to 110°) controls only, and a refrigerator modified to furnish temperature regimes within the range of 35° to 70° with or without light. All tests were made in petri dishes or small plastic boxes. Various substrata were tried, but vermiculite was the most commonly used substratum.

Seedling characteristics were studied in a plastic greenhouse and lathhouse. Most of the studies were set up in nursery flats containing plant bands (fig. 3). Different soils and horticultural mixes were used. Seeds were sown directly into the plant bands. Other studies were conducted in 1-quart to 1-gallon containers filled with soil from a representative site or with mixtures of soil, sand, and vermiculite.

Adaptability to different climates and soils was studied by using transplants, which were planted at several representative sites. These plants were grown from seeds collected at a variety of sites,

[5]*Trade names and company names are used for the benefit of the reader and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.*

[6]*All temperatures are given in Fahrenheit degrees.*

Figure 3.--Seedling characteristics were investigated through studies in nursery flats containing plant bands.

Table 1.--Description of sites in New Mexico where establishment and adaptability of fourwing saltbush were studied

Study site	Elevation	Precipitation		Length of growing season	Soil texture	Principal understory plants
		Annual	October through March			
	Feet	Inches	Percent	Days		
Corona	6,300	15	30	175	Sandy loam	Blue grama, western wheatgrass
Fort Bayard	6,300	14	33	194	Clay loam	Blue grama, side-oats grama
Glorieta Mesa (near Pecos)	7,200	15	29	140	Loam	Blue grama, western wheatgrass
Monica (near Magdalena)	7,500	12	31	123	Sandy loam	Blue grama, ring muhly
Quail Restoration Area (QRA) (near Santa Fe)	6,400	12	33	160	Sandy loam	Blue grama, galleta
Silver Hill (near Magdalena)	6,900	11	31	135	Loamy sand	Blue grama, sand dropseed
Taos Junction (near Tres Piedras)	7,200	13	37	146	Sandy loam	Big sagebrush, blue grama
Wingate (near Gallup)	7,400	12	34	125	Clay	Blue grama, western wheatgrass

principally in Arizona and New Mexico. The plants probably constitute different geographic strains or ecotypes with different site requirements.

Methods of establishment were investigated through hand trials and mechanized seeding tests at several field sites. These involved comparisons between different methods of seedbed preparation and seeding. Seedling emergence and survival, and plant establishment and growth were recorded.

RESULTS AND DISCUSSION

Seed Characteristics

What we commonly refer to as the seed of fourwing saltbush is actually the fruit. Known to botanists as a utricle, the fruit is indurate and thick walled. The true seed, which measures only 1 to 3 mm. long, is enclosed within the fruit (fig. 4). Because of the difficulty of extracting the true seeds, fruits were used in all our investigations. Throughout this report, fruits will be considered as seeds.

Size of seed

Size of seed varies greatly from site to site, plant to plant, and even on the same plant. Length of seed for 117 collections ranged from 2.2 to 9.4 mm., and width of wings from 4.9 to 23.2 mm. Number of seeds per pound ranged from 7,800 to 54,900 for winged seed and from 13,200 to 76,800 for de-winged seed. According to the Woody Plant Seed Manual (U. S. Forest Service 1948), the average for winged seed is 22,500 per pound. Wilson (1928) reported there are 30,000-40,000 seeds per pound. Differences in size and number of seed per pound for eight collections in New Mexico and Arizona are given in table 2.

Seed fill

A high percentage of empty seeds apparently is characteristic of fourwing saltbush. Only slightly more than half of 16,000 seeds from 117 collections throughout Arizona and New Mexico contained

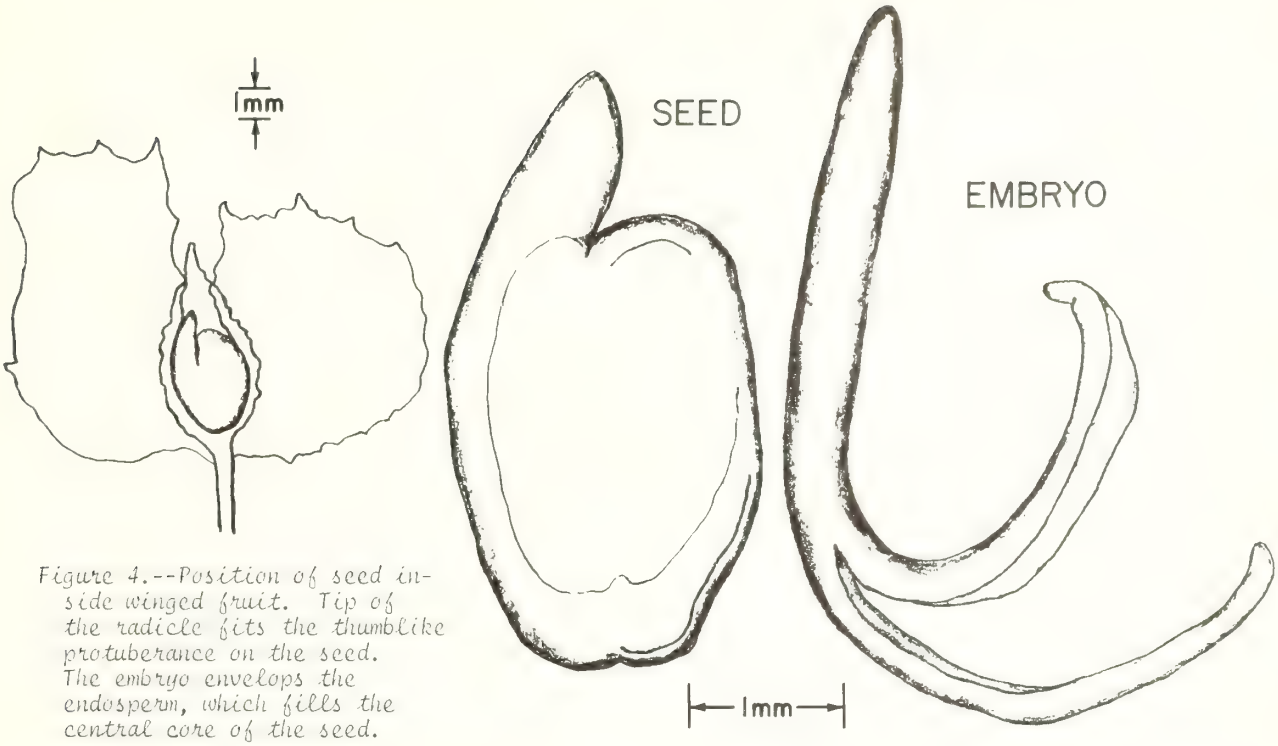


Figure 4.--Position of seed inside winged fruit. Tip of the radicle fits the thumblike protuberance on the seed. The embryo envelops the endosperm, which fills the central core of the seed.

Table 2.--Characteristics of fourwing saltbush seeds collected from eight sources in New Mexico and Arizona

Seed source	Characteristics of collection site			Size of seed		Seeds per pound	
	Geographic location	Elevation	Annual precipitation	Length	Width	Winged	De-winged
		Feet	Inches	Mm.	Mm.	Number	
NEW MEXICO:							
Isleta	1 mile east of Isleta	5,000	9	4.7	12.2	18,000	29,200
Mountainair	5 miles south of Mountainair	6,700	14	4.1	10.7	19,100	38,100
Corona	6 miles west of Corona	6,300	15	4.5	10.4	25,300	38,800
Monica	20 miles west of Magdalena	6,600	13	5.2	11.8	14,800	27,900
Glenwood	3 miles south of Glenwood	4,500	14	3.7	7.0	28,900	51,300
ARIZONA:							
Flagstaff	18 miles northwest of San Francisco Peaks	6,500	17	2.8	8.7	34,000	58,100
Beaver Creek	3 miles southeast of Camp Verde	3,500	14	3.5	9.0	26,600	53,800
Chevelon	30 miles south of Winslow	6,200	15	4.6	13.1	17,500	31,100

embryos. The average was 53.6 percent filled. Two-thirds of the collections had less than 60 percent filled:

Percent fill	Number of collections
1-10	1
11-20	3
21-30	7
31-40	14
41-50	24
51-60	26
61-70	19
71-80	16
81-90	5
91-100	2

No relationship was found between percentage of filled seed and elevation of the collection site. Elevations ranged from 1,400 to 7,800 feet; most were from 4,000 to 7,000 feet.

Percentage of filled seed generally was higher for the larger seeds (table 3). The proportion of seeds containing embryos was highest for seeds classed as large in 105 of the 117 collections. Year of collection only slightly affected the overall average fill percentages.

Source of seed also is a factor (table 4). For example, seeds classed as small in the Caballo collection were longer and wider than those classed as large in the Safford collection; still, all sizes of the Safford seeds were better filled than the Caballo seeds.

Table 3.--Percentage of filled fourwing saltbush seeds of different relative sizes collected, 1960-64

Year of collection	Average filled seeds, by relative size			
	Large	Medium	Small	Average
	- - - Percent - - -			
1960	59.3	57.0	53.3	56.5
1961	57.6	52.7	40.8	50.4
1962	61.8	52.0	45.5	53.1
1963	66.5	59.4	43.8	56.6
1964	61.8	50.2	41.5	51.2
Average	61.4	54.3	45.0	53.6

Table 4.--Relation of size of fourwing saltbush seeds to percent of filled seeds from three collection sites

Seed source	Relative size of seed	Length of seed	Width of wings	Filled seeds
		- - Mm. - -		Percent
Isleta	Large	5.5	14.8	94
	Medium	4.8	11.5	91
	Small	3.9	9.5	91
Caballo	Large	7.2	23.2	53
	Medium	6.1	18.2	25
	Small	5.2	14.0	12
Safford	Large	4.8	10.6	82
	Medium	3.8	8.2	75
	Small	3.2	6.5	65

Table 5.--Percentage of filled fourwing saltbush seeds collected for 5 years from the same plants at four sites in New Mexico

Seed source	Elevation	Filled seeds, by year of seed collection				
		1961	1963	1964	1965	1966
	Feet	- - - Percent - - -				
Corona	6,500	67	51	20	36	25
Isleta	4,900	92	86	92	91	76
Deming	4,300	78	30	59	61	57
Hatch	4,100	41	58	58	39	([1])

[1]Plants destroyed.

The only two collections with more than 90 percent fill were from a single plant near Isleta. Seeds from this particular plant consistently have had a higher fill than seeds from other sources (table 5), which suggests percent fill may be governed primarily by genetic factors, or possibly by site factors. Data for the other sources, however, indicate year-to-year variations in weather or other environmental factors, including prevailing winds, probably are important, too.

Germination data available for seeds from 52 of the collections indicate that fill accounted for 68 percent of the variation in germination ($R = 0.825$, fig. 5).

Cutting tests are recommended on samples of seed so that seeding rates can be adjusted for what

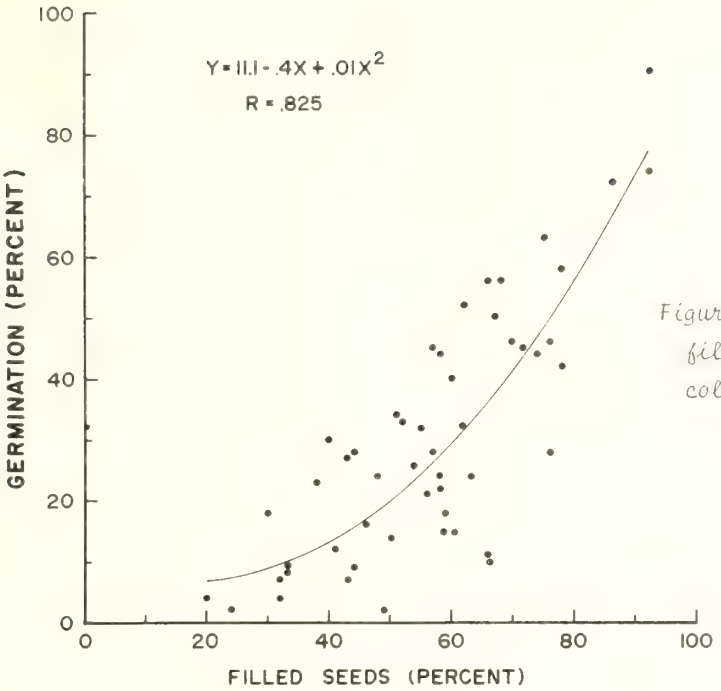


Figure 5.--Relationship between percentage of filled seeds and germination for 52 collections of fourwing saltbush seeds.

very likely will be a high percentage of empty seeds. Fill percentages of less than 40 should be considered substandard. If the smaller seeds have appreciably less fill than the larger seeds, they could be screened out and discarded to improve the efficiency of seeding operations.

Although percent fill probably is partly genetic, information obtained indicates environmental factors also are important. Perhaps seed fill could be improved through cultural practices such as cultivation, irrigation, or fertilization.

Seed Collection and Processing

The seeds are easily collected when they are fully mature. Maturity or ripeness is mainly reflected in color and dryness. Mature seeds usually are a yellow or yellowish orange, and practically air dry. They can be stripped from the branches by hand with little difficulty, and collected in bags, baskets, or on a canvas spread out around the bush. Seeds are sometimes collected with a vacuum-type seed harvester developed by the U.S. Forest Service Equipment Development Center.

To reduce bulk and facilitate handling and seeding, the winged seeds usually are hammermilled. The seeds may be further cleaned in a fanning mill to remove chaff and other debris. Records of Region 3, U.S. Forest Service, showed that 6,181 pounds of winged seed collected in five areas yielded 2,588 pounds of clean, de-winged seed. Hammermilling and cleaning thus reduced the weight by more than 50 percent.

Time of Seed Collection

Time of seed collection could be an important factor affecting germination. An error in judging maturity might result in the collection of immature seeds. Since seeds of fourwing saltbush commonly remain on the bushes from October to April in the Southwest, they can be collected over a period of several months.

Seeds collected from a plant at the Silver Hill site in November 1964 germinated 23 percent in July 1965, whereas seeds collected from the same plant in March 1965 germinated only 10 percent. Similar studies in July 1966 gave different results:

	Collection date	Germination at 66°
Silver Hill	November 17, 1965	33
	April 19, 1966	59
Isleta	December 30, 1965	85
	April 19, 1966	84

The Silver Hill seeds were collected from the same plant as in 1964-65, yet germination was decidedly different; seeds collected in April 1966 germinated appreciably better than those collected in March 1965. The Isleta seeds were collected from the same plant on both dates, and germination of the two collections was nearly identical. Delaying collection of the 1965 crop until April 1966 certainly was not disadvantageous.

Delay in collection of the 1966 seed crop from the plant at Isleta, however, resulted in lower germination. October-collected seeds germinated significantly better than March-collected seeds:

Date seed collected	Date of test		
	April 1967	July 1967	July 1968
	(Percent germination)		
1966:			
October 26	74	86	87
December 30	35	70	81
1967:			
January 27	24	48	82
March 7	20	35	63

Of interest is the improvement in germination with time. By July 1968, germination was about the same whether seeds were collected in October, December, or January.

Afterripening

Seeds of fourwing saltbush apparently undergo afterripening. This process, which usually involves chemical changes that remove germination blocks, may require hours, days, weeks, or months depending on the seed (Pollock and Toole 1961). Seeds of many species are dormant or resting at the time of maturity. They will not germinate, even with favorable moisture and temperature, until they undergo afterripening. Fourwing saltbush seeds frequently have germinated better the second or third year after collection than during the first year.

The afterripening process, for fall-collected fourwing saltbush seeds, appears to be essentially complete in about 10 months. Seeds collected October 23, 1967 from one plant at Isleta were tested at 2-week intervals for a year. Germination patterns were erratic. Germination on the 10th day—a good measure of seed vitality—improved gradually as the seeds aged. When the seeds were 22 weeks old, germination reached a peak, then gradually declined. This peak corresponds to the time of year (late March) when young saltbush seedlings have been observed emerging in nature. This finding supports the idea held by some physiologists that seeds contain built-in "time clocks." Another peak was reached by seeds 38 weeks old, then germination declined, gradually increased, and finally leveled off for seeds 46 to 52 weeks old. Trends in 30-day germination, the more conventional measure of seed viability, generally parallel those of 10-day germination.

Seeds that have essentially completed the afterripening process also germinate more rapidly than freshly collected seeds (fig. 6). When tested only 8 weeks after collection, seeds germinated very slowly; germination was negligible the first 20 days. By contrast, seeds tested 44 weeks after collection germinated rapidly; germination was practically complete in 15 days.

Germination

Imbibition

The uptake of water by the seed, known as imbibition, is the first process that occurs during germination. Composition of the seed, permeability of the seed or fruitcoat to water, and availability of water influence the extent of imbibition.

Our studies show winged seeds of fourwing saltbush are fully imbibed in about 24 hours (fig. 7). Air-dry seeds with wings increased 92 percent in weight when fully imbibed.

De-winged seed imbibed water more rapidly than winged seed and were practically fully imbibed in about 15 hours, at which time they had increased in weight 59 percent.

These results suggest that, when the soil becomes wet, the seeds will imbibe and the germination process can start in 1 day, contingent of course on other environmental factors.

Temperature Effects

Fourwing saltbush seed usually germinates best at relatively low temperatures. The Woody Plant Seed Manual (U.S. Forest Service 1948) recommends testing germination at 77° (day) and 50° (night) for 20 to 30 days. Wilson (1931) reported seeds germi-

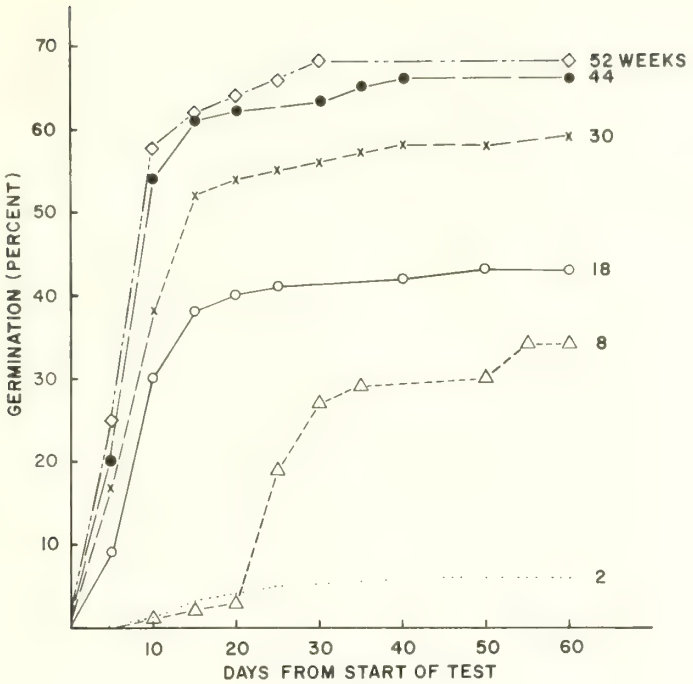


Figure 6.--Afterripening illustrated by germination rates in tests begun 2, 8, 18, 30, 44, and 52 weeks from the date seeds were collected.

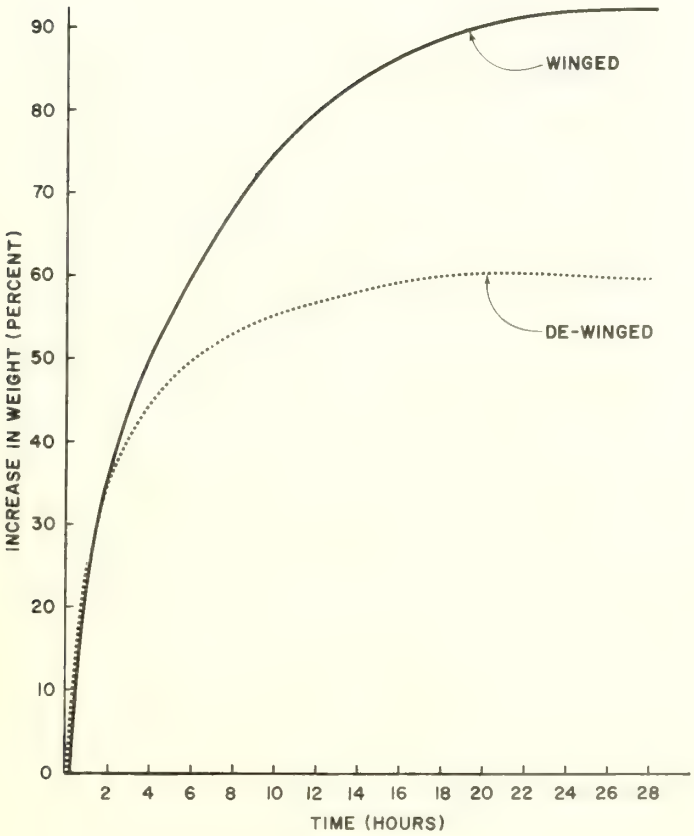


Figure 7.--Imbibition of winged and de-winged fruits of fourwing saltbush (average of four sources--fruits air dry--74°).

nate in the field during cool or cold weather. In Australia, Knowles and Condon (1951) found cool, wet weather was conducive to germination of Atriplex vesicarium, a perennial saltbush. They reported germination seldom is good after summer rains because of high temperatures. Beadle (1952) found the optimum temperatures for five species of Atriplex in Australia fell between 59° and 77°. In Colorado, Hervey (1955) obtained 47 percent germination of fourwing saltbush at 68°, 45 percent at 59°, and 7 percent at 39°. Gerard (1965) reported 55° to 85° as the optimum temperature range for germination of fourwing saltbush seeds collected in southern New Mexico. He obtained highest germination at constant temperatures of 55°, 65°, and 85° and alternating temperatures of 70° (10 hours) and 60° (14 hours).

In our studies, germination of eight sources of seed from Arizona and New Mexico was higher at constant temperatures of 42° and 58° than at 77° (Springfield 1964). Germination of all eight sources averaged significantly less at 77° (fig. 8). Improvement in percent germination at 58° compared with 77° was especially pronounced for the Corona, Glenwood, Flagstaff, and Beaver Creek seed. Though there was a trend toward higher germination at 58° than at 42°, the difference between average germination at these two temperatures was not significant.

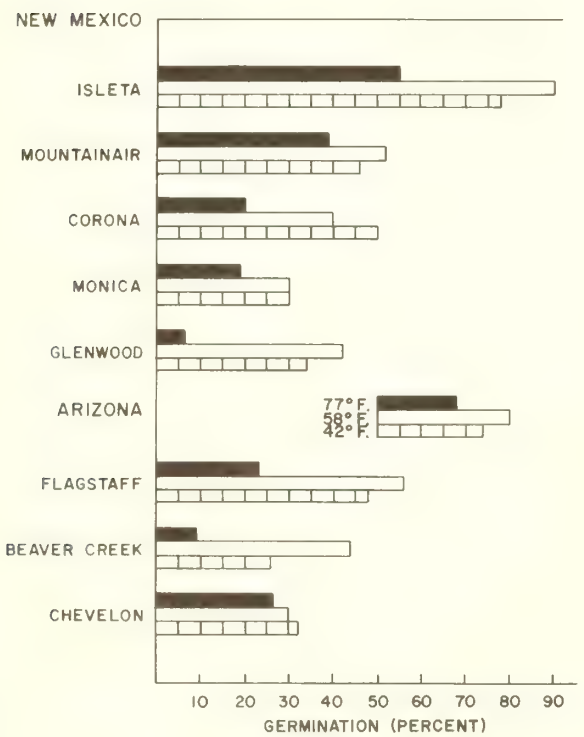


Figure 8.--Germination of eight sources of seed in 36 days at three constant temperatures.

Further studies with 15 sources of seed showed significantly higher germination at a constant temperature of 55° than at alternating temperatures of 86° (8 hours, light)-68° (16 hours, dark). All sources germinated better at the lower temperature.

Intensive investigations with seeds collected from a single plant near Isleta, New Mexico, revealed optimum temperatures for germination were from 55° to 75° (fig. 9). Germination in 30 days was appreciably less at temperatures from 39° to 55° or from 75° to 100°. For the comparisons, alternating temperatures are expressed as weighted mean temperature. Germination at weighted mean temperatures generally averaged less than at the corresponding constant temperature. The higher temperature in the alternation, particularly temperatures exceeding 80°, apparently had a depressing effect on germination. The germination behavior at alternating temperatures seems to be related to the separate effects of the two component temperatures and the time of exposure to each, rather than to be a direct response to hour-degrees such as expressed by weighted mean temperature.

Seeds from the Isleta source began germinating within 2 days at a temperature of 81° and within 3 days at temperatures of 65° and 73° (fig. 10). Germination was nearly complete within 6 days at 65°, 73°, and 81°. At lower temperatures, the start of germination was delayed and the speed of germination was slower.

Moisture

As for all seeds, adequate moisture is essential for the germination of fourwing saltbush seeds. When temperatures are near optimum, however, saltbush seeds apparently will germinate under relatively high moisture stress.

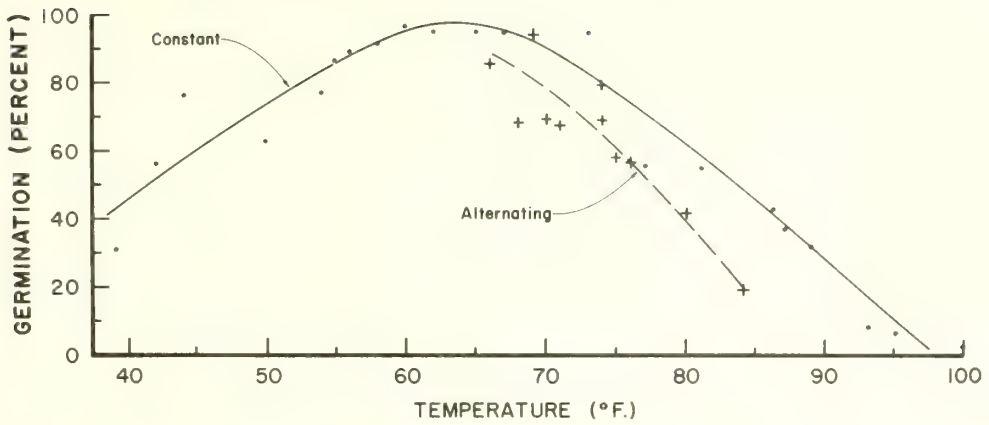


Figure 9.--Germination of Isleta fourwing saltbush seeds at constant and alternating temperatures in a 30-day period.

To determine the effects of moisture stress on the germination of six sources of seed, stresses were induced by different concentrations of mannitol (Springfield 1966).

Total germination decreased as moisture stress increased (fig. 11). Germination at 0.3 and 3 atmospheres (atm.) osmotic stress was greater than at 7, 11, or 15 atm. Isleta and Mountainair seeds germinated significantly better than seeds from the four other sources (table 6). The Mountainair source germinated better than the other sources at stresses of 11 and 15 atm.; seeds from this source may have characteristics that enable them to germinate and become established under relatively dry conditions.

Germination was also delayed by increasing moisture stress (fig. 12). Temperature strongly influenced these delays. Seeds tended to germinate better under the higher stresses at 63° than at 49° or 85°. Seeds germinated well even under the relatively high 7-atm. stress at 63°, which suggests moisture stress may be less important in the germination of saltbush seeds when temperatures are near optimum.

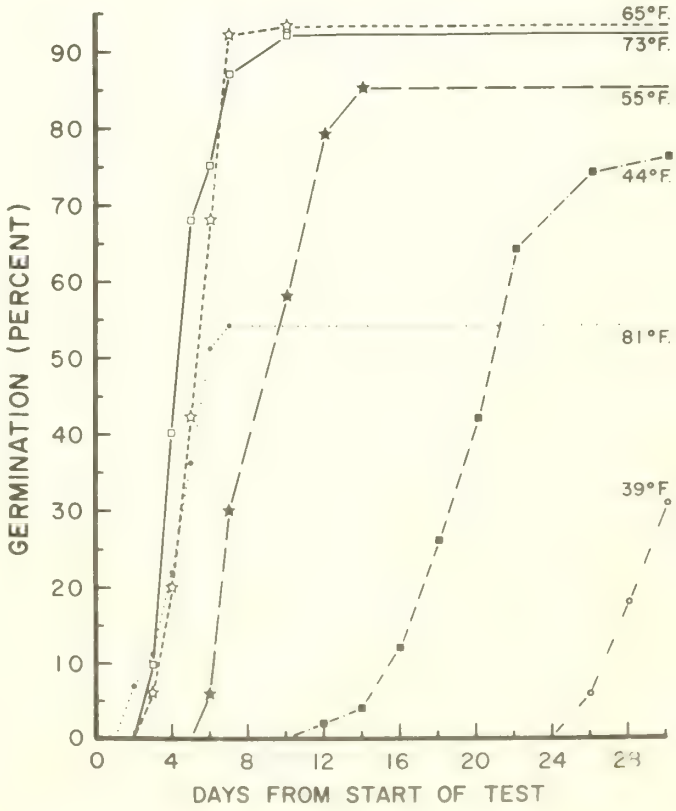


Figure 10.--Speed of germination of Isleta seeds at different constant temperatures.

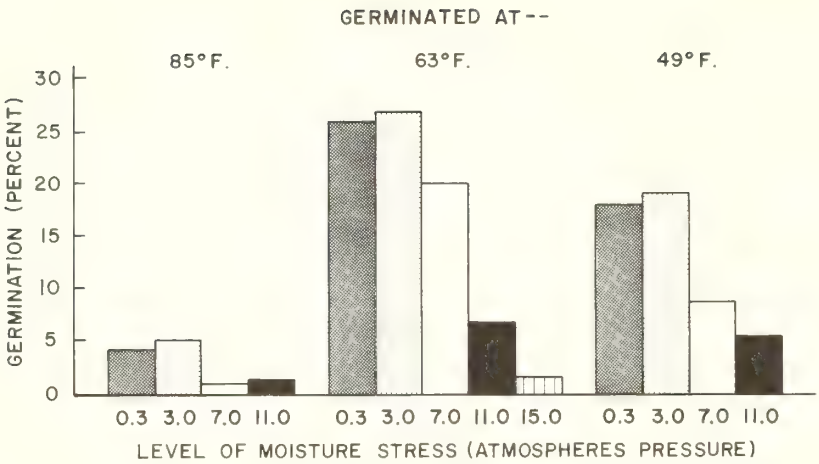


Figure 11.--Average germination of six seed sources at five moisture stresses.

Figure 12.--
Speed of germination at different moisture stresses and temperatures.

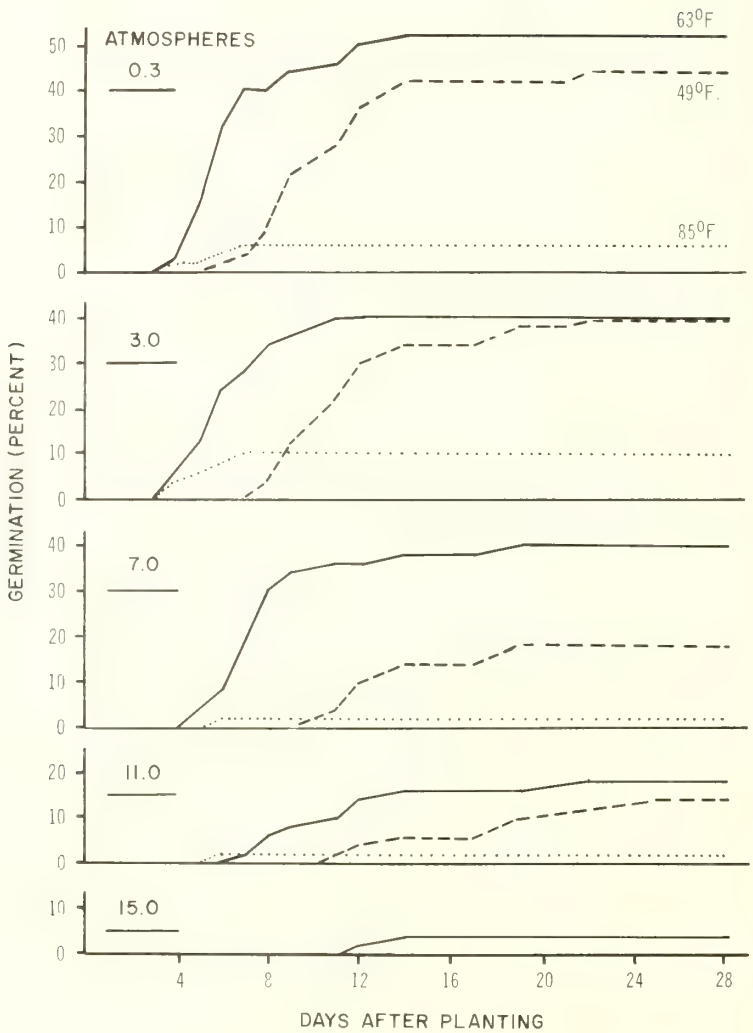


Table 6.--Average percentage of fourwing saltbush seeds that germinated at 63° and 49° at five levels of moisture stress (seed collected from six sources)

Seed source	Germination by levels of moisture stress					
	0.3 atm.	3 atm.	7 atm.	11 atm.	15 atm.	Average[1]
	- - - - - Percent germination - - - - -					
Isleta	60	48	28	12	0	29.6a
Mountainair	34	32	30	20	4	24.0a
Corona	6	12	8	0	0	5.2b
Chevelon	8	24	12	0	0	8.8b
Beaver Creek	16	20	4	6	0	9.2b
Glenwood	8	4	4	0	0	3.2b
Average[1]	22.0a	23.3a	14.3b	6.3c	0.7d	

[1]Values followed by the same letter do not differ significantly at the 0.05 level using Duncan's multiple range test.

Table 7.--Average percentage of fourwing saltbush seeds that germinated in 30 days in periods of continuous darkness and various photoperiods (seeds collected from three sources)

Temperature (°F.)	Daily light	Germination by seed source and collection date			
		San Juan 1963 seed	Isleta 1963 seed	Isleta 1966 seed	Average
	Hours	- - - Percent - - -			
Constant:					
63°	24	55	93	59	69
	0	63	90	49	67
73°	24	53	93	41	62
	0	52	89	29	57
81°	24	41	54	39	45
	0	37	56	15	36
86°	24	23	34	16	24
	0	7	28	3	13
Alternating:					
76° for 12 hours - 62° for 12 hours (Average 69°)	12	61	92	75	76
	0	67	89	67	74
92° for 10 hours - 72° for 14 hours (Average 80°)	10	18	41	15	25
	0	11	16	7	11

Light

Light apparently neither inhibits, nor is required for, germination of fourwing saltbush seeds. Seeds have germinated practically the same in continuous light as in continuous darkness. A source from Continental, Arizona, for example, germinated 21 percent in continuous light and 24 percent in continuous darkness.

Intensive investigations, however, showed some differences in the germination of three sources of seed under various light and dark situations (table 7). Three-year-old seeds held in continuous darkness germinated nearly as well as those exposed to continuous light at constant temperatures of 63°, 73°, and 81°, and at alternating temperatures of 76° (12 hours)-62° (12 hours) with 12 hours of light during the 76° temperature period. Seeds less than 4 months old (collected October 26, 1966, and tested in February 1967), however, germinated less when held in continuous darkness under all temperatures. At 92° (10 hours)-72° (14 hours), all three sources of seed germinated less when held in darkness than when exposed to 10 hours of light daily. Source of light was cool white fluorescent bulbs except at the constant 81°, when Gro-lux bulbs rich in red and blue light were used.

These results indicate light may be required for the germination of freshly collected seed regardless of temperature, and possibly also for older seed when the temperatures are relatively high. How old seeds must be before they no longer require light for germination when temperatures are near optimum is not known for sure, but the available evidence indicates seeds collected in the fall germinate satisfactorily in total darkness the next summer.

Aeration

Fourwing saltbush seeds apparently are sensitive to deficient aeration. No seeds germinated in saturated sand, compared with 51 percent germination in sand three-fourths saturated, and 64 percent in sand half saturated. The failure of seeds to germinate in saturated sand is attributed to deficient aeration. Minimal or optimal levels of oxygen required for germination have not been determined. Germination in 72 hours was significantly reduced when oxygen was held at slightly less than 5 percent (Lavin et al. 1968).

Factors Affecting Viability of Seed

Storage of Seed

Little information is available concerning proper storage of fourwing saltbush seed. The U.S. Forest Service (1948) recommended storing the seed in a dry place, and reported the seeds do not deteriorate appreciably, at least not until the 6th or 7th year after gathering; one lot germinated 19 percent after 9 years in dry, open storage. Hervey (1955) re-

Table 8.--Average percentage of fourwing saltbush seeds that germinated in 33 days, after 3-years' storage, refrigerated seed compared with unrefrigerated seed (seed collected from four sources)

Seed source	Year collected	Unrefrigerated 55° to 90°		Refrigerated 38° to 42°	
		Germination at--		Germination at--	
		Alternating 86°, 68°	Constant 54°	Alternating 86°, 68°	Constant 54°
		- - - - - Percent - - - - -			
Isleta	1961	66	76	70	76
Mountainair	1961	46	60	40	44
Corona	1961	40	66	20	34
Bernalillo	1962	30	24	32	30
Average		45.5	56.5	40.5	46.0

ported no difference in germination of seeds stored for 3 years in sealed containers at 37° to 41°, or stored open or in sealed containers at room temperatures.

Storage at subfreezing temperatures (-5° to -9°) for 2 years at Santa Fe did not affect viability. Average germination of six collections of seed was the same whether they were stored in paper bags at 55° to 90° or in cans at subfreezing temperatures:

	55° to 90°	-5° to -9°
	(Percent germination)	
Seed source:		
Safford	17	22
Flagstaff	4	20
Espanola	5	8
Lamy	24	20
Isleta	64	69
Gran Quivira	44	21
Average	27	27

Refrigeration of seed for 3 years at temperatures from 38° to 42° had no significant effect on viability (table 8). The trend was toward higher germination of the unrefrigerated seeds.

Viability of seed has been maintained for 6 years under ordinary storage conditions. Seeds collected in 1961 and stored in paper bags at temperatures from 55° to 90° germinated as well in 1967 as in 1963 (table 9).

Table 9.--Average percentage of fourwing saltbush seeds that germinated 1963-67 (seed collected in 1961 and stored in paper bags at 55°-90° temperatures)

Year germination tested	Germination temperature (constant or alternating)	Average germination	
		Isleta	Corona
	°F.	Percent	
1963	42	56	50
	58	90	40
	77	55	20
1965	50	62	46
	78, 58	67	36
	86, 68	48	36
1966	78, 58	75	41
	86, 68	75	34
1967	64	79	47

Table 10.--Average percentage of fourwing saltbush seeds that germinated in 1968 at 56° from four sizes of seeds collected from one plant at Isleta in 1966 and 1967

Size of seed	Treatment	Germination of seed collected in--		
		1966	1967	Average
		- - Percent - -		
Large	Winged	85.3	84.0	84.6
	De-winged	85.3	85.3	85.3
Medium	Winged	80.0	84.0	82.0
	De-winged	84.0	81.3	82.6
Small	Winged	81.3	89.3	85.3
	De-winged	88.0	84.0	86.0
Very small	Winged	84.0	81.3	82.6
	De-winged	80.0	77.3	78.6

Age and Size of Seed

Fourwing saltbush seeds retain their viability for many years. Some lost only about half their germinative energy in 16 years. These seeds, collected in October 1951 near Fort Collins, Colorado, germinated 20 percent the first year (Hervey 1955). Three years later, the seeds germinated 24 percent; tests indicated a potential germination of 32 percent. In November 1968, these seeds—stored at room temperatures—germinated 10 percent. Tetrazolium tests indicated a potential germination of 24 percent. Thus, the potential germination declined only one-fifth although the actual germination dropped one-half during the 16 years.

Size of seed does not appear to be an important factor provided the seeds are well filled. Four sizes of seeds from the plant at Isleta germinated about the same (table 10).

Effect of Year of Collection on Seed Viability

Seed viability varies with year of collection. Many factors undoubtedly affect the viability of each year's seed crop: age of the plants, proximity and ratio of male to female plants, moisture and temperature conditions during flowering and seed formation, wind movement, and insects.

Collections from the same individual plants at two sites for 4 years showed seeds from the plant near Isleta consistently had a high germination percentage whereas those from the plant near Corona gave erratic results. Average germination in 1966 at alternating temperatures, 78° (12 hours) - 58° (12 hours), was:

	Isleta	Corona
	(Percent germination)	
Seed collected:		
1961	75.3	41.3
1963	68.7	8.0
1964	66.0	3.3
1965	62.7	6.7
Average	68.2	14.8

This suggests the Isleta plant may represent a geographic or ecotypic strain with above-average seed viability.

Seed Treatments

De-winging the seed.—Removing the wings from the seed is an accepted practice. Advantages of de-winging are (1) ease of handling, especially when seeds are to be planted with a drill or other mechanical seeder, (2) reduction in bulk, and (3) easier coverage with soil. The usual procedure is to run the winged seeds through a hammermill.

De-winging the seed did not significantly affect final germination percentages. For all studies conducted from 1963 to 1968, winged seeds germinated 54 percent compared with 58 percent for de-winged seeds. In a study of eight sources of seed germinated at three temperatures, no significant difference was found in germination between winged and de-winged seed (table 11). Of the eight sources, only the de-winged Monica seed showed consistently higher germination. The de-winged seed germinated more quickly, however (fig. 13). Under temperatures of 77° and 58°, more than twice as many de-winged as winged seed had germinated by the 6th day. But by the 10th day at 77° and by the 24th day at 58° germination of the winged seed practically equaled that of the de-winged seed. This faster germination of de-winged seed may be desirable because favorable combinations of temperature and soil moisture are usually of short duration on southwestern ranges.

Additional studies showed de-winging the seed by hand or cleaner, as well as by hammermill, does not affect total germination. Seeds from Navajo Canyon, in northwestern New Mexico, were processed several ways; results of germination tests

Table 11.--Average percentage of winged and de-winged fourwing saltbush seeds that germinated in 36 days at three constant temperatures (seed collected from eight sources)

Seed source	Germination at constant temperature of--					
	76.6°		57.6°		41.8°	
	Winged	De-winged	Winged	De-winged	Winged	De-winged
	- - - - - - - - Percent - - - - - - - -					
Isleta	60	50	92	88	76	80
Mountainair	36	42	48	56	60	32
Corona	14	26	40	40	44	56
Monica	12	26	12	48	24	36
Glenwood	10	2	40	44	32	36
Flagstaff	26	20	48	64	44	52
Beaver Creek	6	12	48	40	28	24
Chevelon	22	30	44	16	32	32
Average	23.3	26.0	46.5	49.5	42.0	43.0

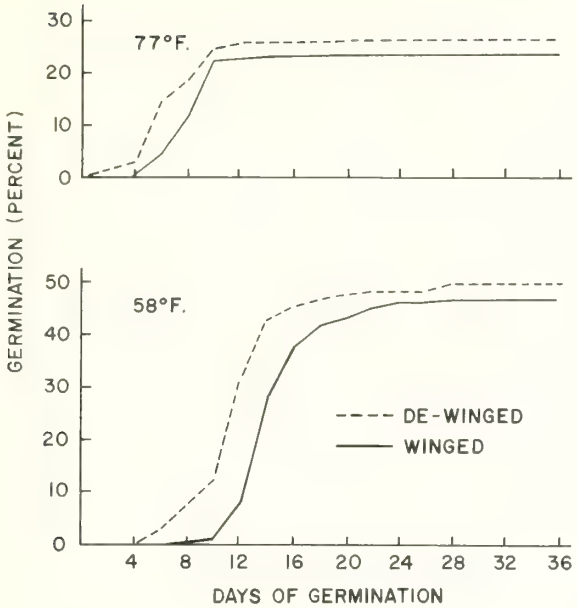


Figure 13.--Average germination rate of winged and de-winged fourwing saltbush seed from eight collection sites, at two temperatures.

under alternating temperatures of 86° (8 hours, light)-68° (16 hours, dark) were as follows:

	Percent
Winged seed	25.6
De-winged by:	
Handrubbing	26.0
Hammermilling	22.4
Dybvig cleaner	27.6

The differences in germination were not significant.

These findings are in accord with Hervey (1955), who reported 17 percent germination for hammermilled seed compared with 20 percent for winged seed.

Scarification.—Scarification of the seedcoats has not consistently improved the germination of fourwing saltbush in our studies, which does not agree with results reported from California (Nord and Whitacre 1957) where heavy scarification increased germination substantially.

Investigators who reported improved germination from de-winging or scarification have used hand treatments, in which seeds were rubbed between layers of sandpaper (Gerard 1965, Nord and Whitacre 1957).

In preliminary studies, we compared mechanical treatments with various hand treatments. Seeds collected in 1963 from Isleta and Lamy were planted in nursery flats. Percent germination from various seed treatments was as follows:

	Isleta	Lamy
	(Percent germination)	
Seed treatment:		
Not treated (winged)	41	48
Hand treated--		
De-winged	56	46
Rubbed	46	37
Scarified	11	52
Mechanically treated--		
De-winged	7	2
Scarified	0	0

Hand de-winging improved germination of the Isleta seeds, which agrees with Gerard's (1965) results, but did not affect germination of the Lamy seeds. Hand scarification was detrimental to the Isleta seeds; seeds of this source have relatively thin-walled seedcoats, so they may have been over-scarified. Hand rubbing (between gloves) removed most of the wings but did not scratch the seedcoat; yet this treatment lowered the germination of Lamy seed, perhaps by damaging the embryo. Mechanical treatment was definitely detrimental.

Later, more intensive studies showed that effects of scarification vary with the source of seed and seedcoat characteristics. Seeds with moderately thin seedcoats were damaged by mechanical scarification with abrasives (table 12). Even light scarification was detrimental. On the other hand, seeds with thick seedcoats apparently were benefited by very light scarification. Our scarification treatments, performed in a small electric scarifier lined with sandpaper, may have been too severe for most seeds. Microscopic examination revealed many of the treated seeds had relatively large holes in the seedcoat; the percentage of such seeds increased with the number of seconds of scarification treatment.

Germination tests were made on seeds classified according to degree of seedcoat abrasion. Germination of the thinner walled seeds from Deming and Isleta was reduced significantly whenever scarification caused a break or hole in the seedcoat. By contrast, germination of the thicker walled seeds

Table 12.--Extent of scarification damage[1] to fourwing saltbush seeds, and resultant germination

Source of seed	Rating of seedcoat[2]		No treatment (control)		Scarification treatment									
					Very light (20)		Light (40)		Medium (60)		Heavy (80)		Very heavy (100)	
	Thickness	Hardness	Winged	De-winged	Seedcoat damage	Germination	Seedcoat damage	Germination	Seedcoat damage	Germination	Seedcoat damage	Germination	Seedcoat damage	Germination
			Percent germination		Percent									
Deming	2	3	70.7	61.0	18	32.3	32	23.0	38	7.7	44	9.3	54	4.0
Isleta	2	2	96.3	88.7	28	60.7	36	37.3	48	2.7	60	1.3	74	0
Madrid	4	3	53.3	65.0	2	83.7	16	34.7	30	32.7	58	23.0	50	23.0

[1]Percentage of seeds with large holes in seedcoat because of scarification treatment; numbers in parentheses indicate seconds in electric scarifier lined with sandpaper.
[2]Rating scale: Thickness-- 1 = thin, 4 = very thick Hardness-- 1 = hard, 4 = very hard.

from Madrid was not affected by small holes or breaks in the seedcoat. Seeds with large holes in the seedcoats gave negligible germination, however, regardless of source of seed and thickness of the seedcoat.

These results, coupled with results of other supplemental studies, suggest scarification should be used with caution. The proper degree of scarification could improve the germination of thick-walled seeds. Nevertheless, care should be taken to prevent overscarifying the seed to the point where large holes form in the seedcoat.

Chemical Treatment of Seeds

Various chemical treatments have been tried in an attempt to increase germination of fourwing saltbush seeds. None proved satisfactory.

Thiourea.—Universally used to stimulate seed germination, thiourea did not improve the germination of fourwing saltbush. In fact, results of our investigations indicate thiourea may inhibit germination of this species. Two sources of seed (San Juan and Deming) soaked 10 to 30 minutes in 3 percent thiourea germinated less than untreated seeds. Average germination of fourwing saltbush seed in 30 days at 86° (8 hours)-68° (16 hours) was:

	San Juan	Deming
	(Percent germination)	
Untreated	43	21
Seeds soaked in 3 percent thiourea:		
10 minutes	13	8
20 minutes	12	5
30 minutes	6	5

Soaking only 3 to 6 minutes proved less detrimental, but no stimulatory effect was found. Average germination of seeds from Navajo Canyon and Bernalillo planted similarly but with different soaking treatments was:

	Navajo Canyon	Bernalillo	Average
	(Percent germination)		
Seed treatment:			
None	30.0	45.3	37.6
Water, 4 hours	22.0	32.0	27.0
Thiourea			
3 minutes	16.0	37.3	26.6
6 minutes	16.7	43.3	30.0
Water, 4 hours, plus thiourea			
3 minutes	22.7	26.0	24.4
6 minutes	8.7	24.0	16.4

Hydrogen peroxide.—Although it has been shown to hasten and increase the germination of certain tree seeds, hydrogen peroxide reduced the germination of fourwing saltbush. In a test with four sources of seed, soaking for 48 hours in 6 percent peroxide gave these results:

	Peroxide	No peroxide
	(Percent germination)	
Germination temperature:		
49°	8	16
55°	7	33

In another test, seeds soaked a half-hour in 30 percent peroxide germinated only 7 percent compared with 54 percent for untreated seeds (Riffle and Springfield 1968). Further studies with alow-germi-

nating seed source showed that as little as 10 minutes of soaking in peroxide (30 percent) was detrimental.

Citric acid.—As with peroxide, citric acid has been reported to improve the germination of certain tree seeds. The citric acid was neither helpful nor harmful in concentrations of 0.02, 0.05, 0.10, 0.5, 1.0, and 2.0 percent tested on three sources of seed.

Sulfuric acid.—Although other investigators have claimed sulfuric acid improves the germination of fourwing saltbush, our results with this chemical are inconclusive. Boyd (1956) reported seeds treated in concentrated sulfuric acid for 60 minutes germinated 15 percent compared with 10 percent for untreated seeds. According to Gerard (1965), treatment in sulfuric acid for 40 minutes increased germination.

In our studies, two sources of seed treated with concentrated sulfuric acid germinated no better than untreated seeds. Because of its thick, hard seedcoat, the Madrid source in particular was expected to show improved germination when treated with acid. But, as the results below indicate, percentage germination of seeds from two sources was about the same regardless of treatment:

	Deming	Madrid
	(Percent germination)	
Untreated	61	41
Sulfuric acid:		
20 minutes	60	45
40 minutes	57	56
60 minutes	42	38
80 minutes	63	54

The lower germination for seeds treated 60 minutes is puzzling. None of the differences in germination, however, are significant statistically.

Acid-treated seeds imbibed water more rapidly than untreated seed. After 5 hours in a moist medium, acid-treated seeds had increased in weight 79 percent compared with 59 percent for untreated seeds.

Stratification

Results from several stratification studies were not consistent. We stratified seeds by putting them in moist vermiculite at 38° to 42° for 30 days.

In one study with three sources of seed, stratification apparently was harmful:

Seed source and year collected:	Seeds stratified	Seeds not stratified
	(Percent germination)	
Flagstaff (1961)	14	18
Datil (1962)	4	23
San Juan (1963)	17	27

In another study, however, stratification appeared to improve the germination of two of four sources of seed (table 13).

Soaking Seeds to Remove Inhibitors

Inhibitors in the seedcoat and bracts have been suspected of being responsible for the generally low germination of fourwing saltbush. Germination of other species of Atriplex in Australia was found to be inhibited by substances diffusing from the fruit bracts, and the inhibitor was classed as a chloride (Beadle 1952). Studies with an annual

Table 13.--Effects of different periods of stratification on the percent germination of four sources of fourwing saltbush seeds

Seed source	Germination in 30 days at 86° (8 hours); 68° (16 hours)			
	Not stratified	Stratified 10 days	Stratified 20 days	Stratified 30 days
	- - - - Percent - - - -			
San Juan	53	47	60	55
Isleta	40	32	43	46
Continental	8	10	27	30
Deming	37	37	47	51
Average	34.5	31.5	44.2	45.5

Atriplex in Israel (Koller 1957) indicated the presence of a water-soluble inhibitor that in nature is leached from the fruit bracts by rain water. Other studies in California showed enough saponin in the bracts of fourwing saltbush to reduce germination (Nord and Van Atta 1960). Twitchell (1955) found that soaking saltbush seed in water for several hours removed more that 90 percent of the chloride present and increased germination. Drying the seed for 7 days before planting gave higher germination than planting the wet seed. Similar studies by Nord and Whitacre (1957) showed that 4 hours of soaking followed by 8 days of drying did not affect germination in the laboratory.

In our studies we seldom have found any advantage to soaking the seeds in water. For example, two sources of seed were soaked 8 hours, then dried for 52 days. Germination of these seeds at two temperatures was as follows:

	Isleta	Mountainair
	(Percent germination)	
Germination temperature and seed treatment:		
73.3°		
Soaked	24	43
Not soaked	52	38
54.5°		
Soaked	66	58
Not soaked	70	60

The Isleta seed tended to germinate better when not soaked, and the Mountainair seed germinated about the same regardless of treatment. Another study with 2-year-old seed from Rowe, New Mexico, gave similar results.

Continuous washing in water for 2 or 4 hours did not improve germination. Two-year-old seeds from Deming, New Mexico, germinated essentially the same whether they were soaked or washed table 14). Germination was not improved by drying seeds 7 days after soaking or washing. Winged and de-winged seed responded similarly to the different treatments, except that de-winged seeds soaked 4 hours, then dried 7 days, germinated less than seeds treated other ways, for some unexplained reason.

Results of one study indicated soaking in water for 12 hours was detrimental. Percent germination in 30 days at 78° was as follows:

	San Juan	Isleta
	(Percent germination)	
Seed treatment:		
Not soaked	52	62
Dry chill (12 hours, 41°)	56	66
Warm soak (12 hours, 69°)	6	0
Cold soak (12 hours, 41°)	10	0

Soaking seeds in hot water definitely was harmful. Seeds were placed in boiling water and allowed to cool to room temperature—total soaking time 9 hours. Eight sources of seed treated in this manner germinated significantly less than unsoaked seeds.

Determining Seed Viability with Tetrazolium

A rapid test, with tetrazolium chloride (TZ) has been found useful for estimating seed viability of several species (Colbry et al., 1961). In the presence of TZ, living tissues stain red whereas nonliving or weak tissues do not. The principal advantage of the test is that results are available in hours rather than in weeks. Another advantage is that dormant seeds will stain red if they are viable. Thus the test gives an estimate of potential germination, which is especially valuable when seeds exhibit varying degrees of dormancy. Boyd (1956)

Table 14.--Effect on percent germination of seeds soaked or washed in water

Seed treatment and length of time treated	Germination in 30 days at 57°			
	Winged seeds		De-winged seeds	
	Dried 7 days	Not dried	Dried 7 days	Not dried
	- - - Percent - - -			
Soaked in water:				
2 hours	43	47	44	23
4 hours	36	29	15	39
Washed in water:				
2 hours	27	43	44	43
4 hours	39	35	33	35
Not treated	45	--	45	--

reported the embryos of fourwingsaltbush can be stained with TZ.

Several concentrations of TZ were tried on eight sources of seed at different temperatures. The most satisfactory concentration was 0.2 percent. Degree of staining was scored from 0 to 4. Color intensity as well as pattern of staining were considered in assigning the ratings (fig. 14).

Staining of the embryos varied with source of seed. Of the eight sources tested, only seeds from Isleta consistently exceeded 50 percent well-stained embryos (ratings 3 and 4). Seeds from Monica had fewer than 20 percent well stained. A moderately high percentage of the seeds from all sources contained embryos with stain ratings of 2. This rating was assigned to embryos with incomplete staining of the cotyledons or other irregularities in stain patterns. All embryos rated 2 showed brightly stained radicles.

We attempted to correlate TZ stain ratings with germination results. The highest correlation ($r = 0.913$) was between germination percentages and the sum of ratings 2, 3, and 4 (fig. 15). Apparently, the embryo must be rather completely stained to be classed as viable, but minor irregularities in stain patterns such as included in rating 2 probably do not indicate a nonviable embryo. Instead, such embryos may be somewhat less vigorous or slightly deformed, but probably produce seedlings with a reasonable chance for survival. Embryos with 0 or 1 stain ratings, however, would not be expected to develop into normal seedlings.

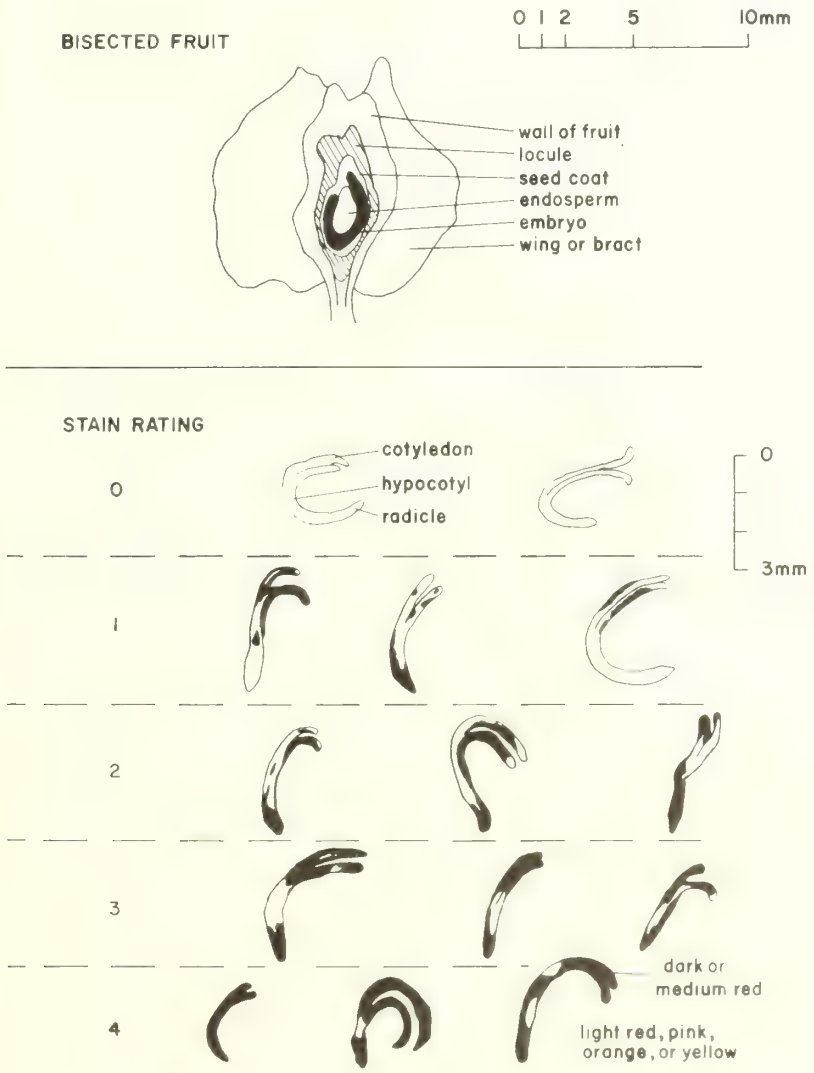


Figure 14.- Tetrazolium stain patterns and ratings.

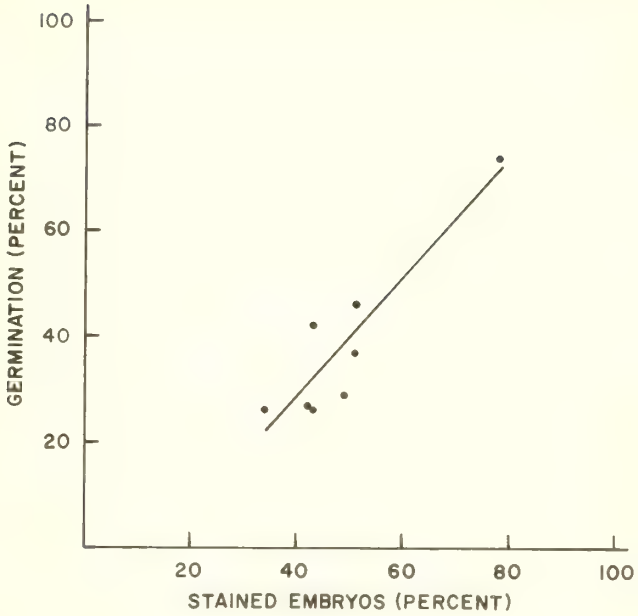


Figure 15.--Relationship between TZ ratings (percentage of seeds with embryos stained 2, 3, and 4 by tetrazolium) and average germination in 36 days at temperatures of 77°, 58°, and 42°. (r = 0.913)

The comparison between seed viability as determined by TZ stain, and actual germination was closer for some sources of seed than others (fig. 16). Closest in agreement were the Isleta, Mountainair, and Flagstaff seed; the two methods agreed within 5 percent or less. Three of the remaining five sources agreed within 8 to 15 percent. Poorest agreement was for the Beaver Creek and Chevelon sources. Seed dormancy is suspected where germination was substantially less than the viability indicated by TZ staining.

Seedling Characteristics

A variety of studies were conducted to determine seedling emergence, mortality, and growth in different soils. These studies were made outdoors with no control over temperature. Moisture was held near field capacity for most studies.

Emergence and Mortality

Seedlings begin emerging within 6 to 10 days, provided moisture is adequate and temperatures are not extreme. Germination is epigeous. Usually the first visible sign of emergence is an arched hypocotyl (fig. 17). The seed ordinarily remains in the soil, but sometimes it is lifted above the surface and remains attached to the cotyledons several days; this happens more often with dewinged seed and in shallow seedings. Emergence usually is complete within 12 to 20 days.

Seedling emergence and growth are largely dependent on temperature and moisture. In studies with 1-year-old seeds from Delta, Colorado, planted in a sandy loam soil March 18, most of the seedlings emerged during a period when air temperatures ranged from 68° - 75° during the day and 37° - 42° at night (table 15). Height growth was greatest when day temperatures were about 80° and night temperatures about 46°.

Seedling emergence varies widely with source of seed. This undoubtedly reflects differences in seed fill, and possibly physiological makeup among seed sources. In one study, eight sources of seed were germinated in soil obtained from beneath a mature saltbush. Seeds were planted in flats August 26; final seedling counts were taken October 7. Soil was kept moist by daily sprinkling in August and at 2- to 5-day intervals thereafter. Daytime temperatures during the first 2 weeks ranged from 78° to 92°; night temperatures from 54° to 70°. Emergence and mortality of seedlings varied widely:

Seed source	Emergence	Mortality
	(Percent)	
Arizona:		
Flagstaff	24	12
Tuba City	27	0
New Mexico:		
Corona	27	12
Glenwood	57	0
Hatch	12	0
Lovington	45	33
Magdalena	21	29
Monica	30	20

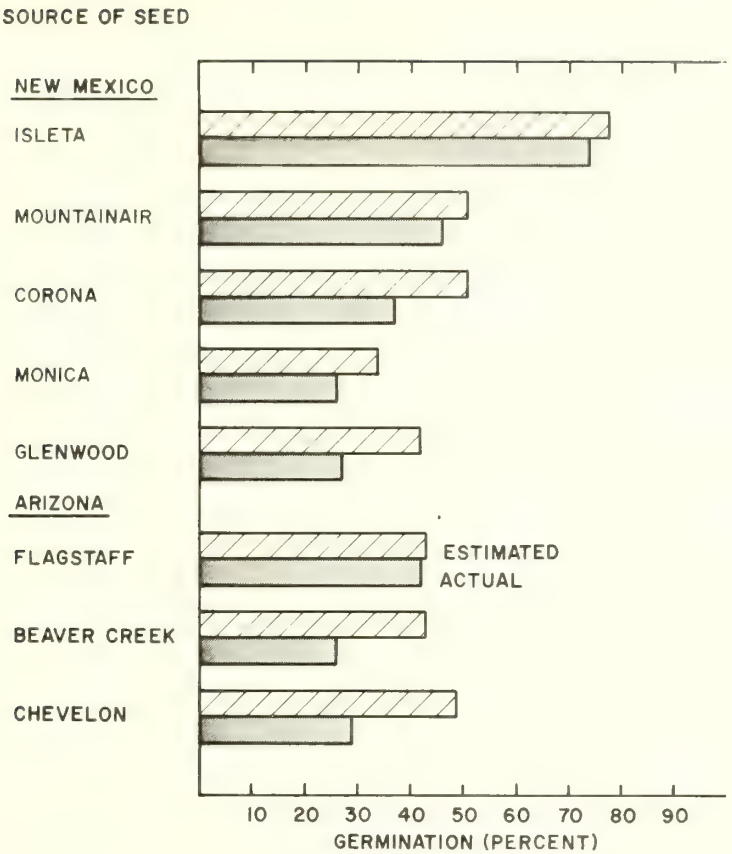
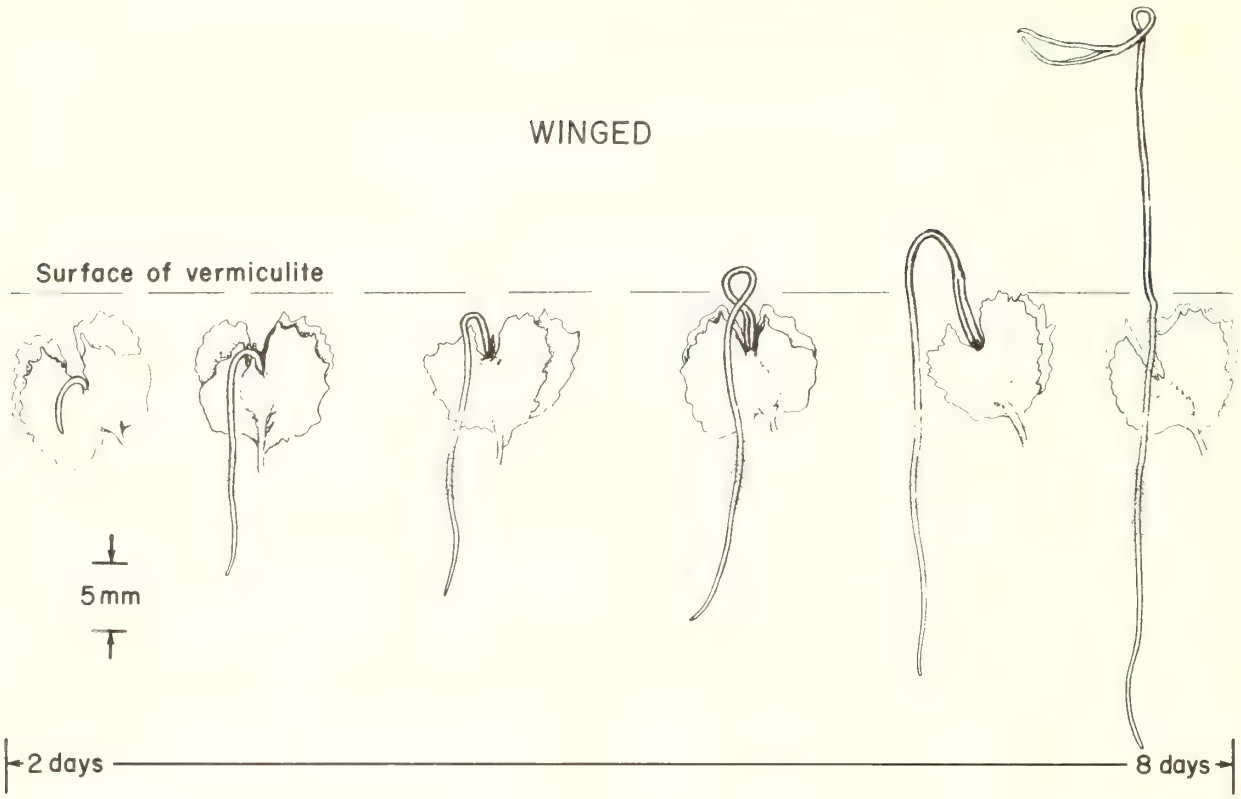


Figure 16.--Comparison between estimated potential germination percentages (TZ-stained embryos, rated 2, 3 and 4) and average actual germination percentages (at 77°, 58°, and 42°) for eight sources of fourwing saltbush seed.

Table 15.--Seedling emergence and height growth from 1-year-old seeds planted in sandy loam soil, March 18 (Seed source: Delta, Colorado)

Date measured	Seedling development		Weather conditions between dates		
	Emergence	Height growth	Precipitation	Maximum temperature	Minimum temperature
	Percent	Inches	Inches	- - - - °F. - - - -	
April 7	24	0.5	0.58	68	37
14	36	.8	.24	75	42
21	40	1.1	.45	82	48
29	40	1.4	.38	72	42
May 12	40	4.0	.82	80	46
30	45	6.1	1.33	81	47



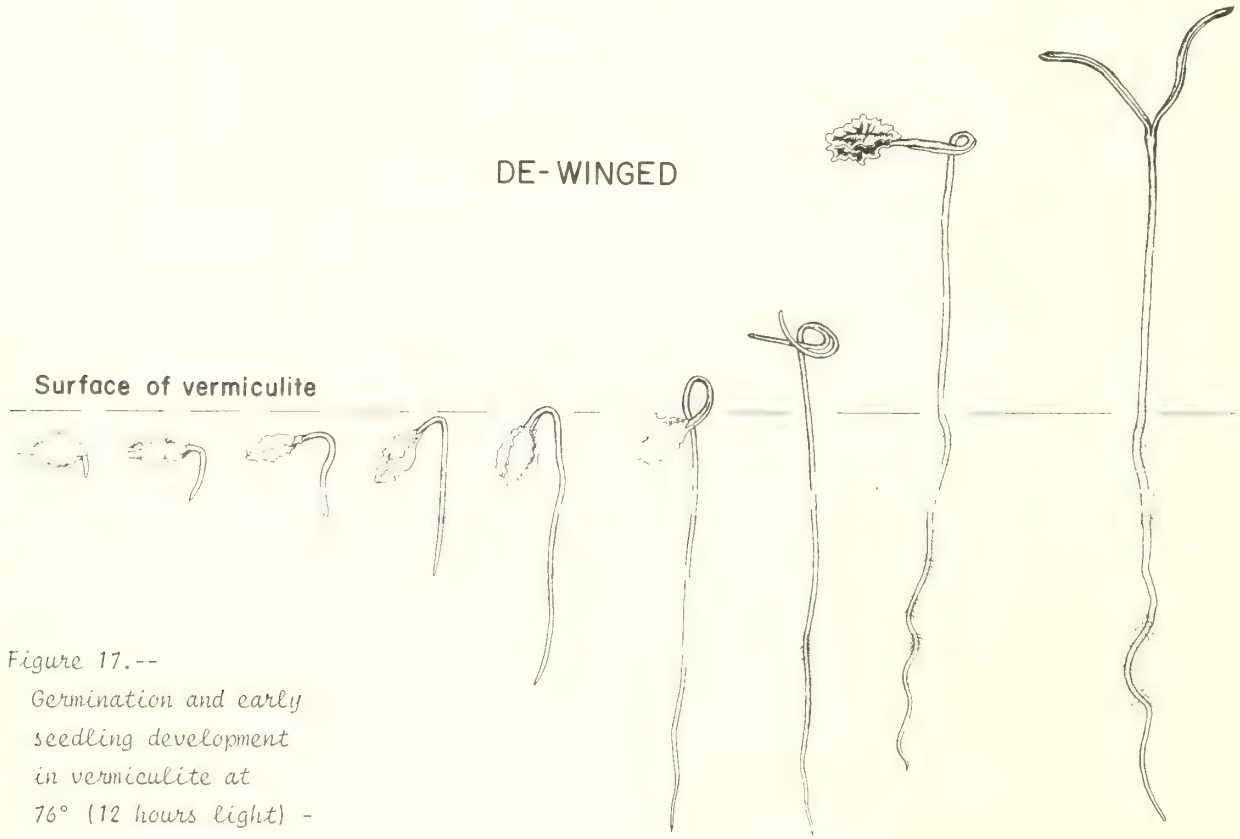


Figure 17.--
Germination and early seedling development in vermiculite at 76° (12 hours light) - 60° (12 hours dark).

Studies conducted in a representative pinyon-juniper soil obtained near Santa Fe produced similar results. Seeds were planted September 12, seedlings began emerging September 20, and final counts October 14 showed the following:

Seed source	Emergence	Mortality
	(Percent)	
Arizona:		
Benson	27	0
Willcox	15	26
New Mexico:		
Corona	69	0
Glenwood	62	0
Hatch	48	8
San Felipe	7	0
Utah:		
Ephraim	33	19

Seedling mortality was less in sandy loam soil than in other substrata in another nursery study. Two-year-old seed from Chevelon, Arizona, were planted in nursery trays filled with different substrata. Day temperatures ranged from 75° to 88° and night temperatures from 43° to 62°. Results were as follows:

Substrate	Emergence	Mortality
	(Percent)	
Sandy loam	28	0
Perlite	40	20
Vermiculite	24	33

Since the perlite and vermiculite are relatively inert and not apt to contain disease organisms, mortality presumably was caused by seedborne organisms. Poorer aeration in the perlite and vermiculite than in the sandy loam soil could have been a contributing factor.

Treatments to Control Disease Organisms

Mortality of fourwing saltbush seedlings sometimes is extremely high. Examination of seeds and seedlings has revealed contamination by Alternaria and Fusarium (Riffle and Springfield 1968). In one nursery study with 2-year-old seed from Mountainair, conducted under low light intensity when daytime temperatures ranged from 78° to 94°, mortality varied from 88 to 100 percent. In a hand-seeding trial at the Corona site, seedling establishment was higher from fungicide-treated seeds than from untreated seeds. The number of seedlings per foot of row with seeds from Isleta and Corona was:

	Isleta	Corona
	(Number)	
Dusted with Arasan	2.5	1.0
Not treated	.5	.5

Fungicidal treatment of seeds has not always reduced seedling mortality. In a nursery study with 1-year-old Lordsburg seed, when daytime temperatures were 48° to 62° and night temperatures 25° to 36°, results were as follows:

Seed treatment	Emergence	Mortality
	(Percent)	
None	16.3	0
Soaked 8 hours	20.7	19
Not soaked - fungicide	45.7	0
Soaked 8 hours - fungicide	37.3	23

Although mortality was not affected, fungicidal treatment (Captan) significantly increased emergence. Perhaps the fungicide was effective in controlling seedborne organisms that were detrimental to seedling emergence. These results are in disagreement with those reported by Hervey (1955), who found fungicidal treatment of seeds did not affect germination.

Control of soil pathogens through fumigation improved seedling establishment in two of three soils studied. Highest seedling establishment resulted from fumigation of Wingate soil. The number of established seedlings per 100 seeds planted in three soil types was:

	Soil type		
	Wingate	Silver Hill	QRA
	(Number)		
Soil and seed treatments:			
Soil fumigated			
Fungicide	37	3	10
No fungicide	20	7	23
Soil not fumigated			
Fungicide	13	7	3
No fungicide	10	0	0

Seeds were planted 0.5 inch deep. Soil moisture was kept near field capacity for 2 months. Seedlings emerged and became established more readily in the Wingate clay soil than in the Silver Hill loamy sand or QRA heavy sandy loam. These figures suggest harmful micro-organisms could be present in the Wingate and QRA soils. Dusting seeds with fungicide (Arasan 75) was beneficial only for seedlings in the Wingate soil.

Growth in Different Soils

Fourwing saltbush seedlings generally grow better in soils from representative sites than in horticultural mixes. For these growth studies, 2- to 4-week-old seedlings were transplanted to gallon containers filled with different soils or mixes. Heights of 10-month-old seedlings grown from the Isleta seed source, for example, were as follows:

	Average height (Inches)
Soil collected from under:	
Mature saltbush	12.8
Pinyon	11.8
Cercocarpus	10.2
Blue grama	8.2
Winterfat	8.0
Horticultural mix (2 parts sand, 1 part peat, 1 part loam)	3.9

Studies with five other sources of saltbush showed 1-year-old plants generally grew taller in soil from the Santa Fe area (table 16). Four of the sources grew best in a soil taken from beneath shrubs (cercocarpus) near Santa Fe (fig. 18). Poorest growth was in a grassland soil from the Rio Puerco. Height growth also was relatively poor in Corona soils, both those from beneath grass and juniper trees. Growth was poorer than expected in soil collected near Magdalena beneath mature saltbush plants.

Methods of Establishment

Methods of establishment have been studied at several sites representative of the pinyon-juniper type (see table 1). These sites range in elevation from 6,300 to 7,500 feet. Soils vary from loamy sand to clay. Though most were hand trials, some of the methods involved mechanized equipment. The most comprehensive tests were conducted at the Monica site, where different kinds of tractor-drawn equipment were compared for site preparation and seeding.

Direct Seeding

Small-Scale Field Trials

Investigations included comparisons among various depths of furrows, mulching, and soil-firming treatments.

Seedling establishment was about the same in shallow furrows (1 to 2 inches deep) as in deep furrows (3 to 4 inches deep) at the Silver Hill site. The number of seedlings per foot of row (10 seeds) that became established from a July seeding was:

	Shallow	Deep
	(Number)	
Seed source:		
Corona	0.5	0.6
Deming	.1	.2
Isleta	.1	.0
Gran Quivira	.4	.2

Some sloughing of the sandy soil from the sides of the furrows may have covered seeds too deeply, especially in the deep furrows. Natural sloughing of the soil resulted in complete failure from a June seeding in deep furrows at the Monica site.

Removal of competing vegetation would seem to be necessary for satisfactory seedling establishment. Three methods of seedbed preparation were compared at the Monica site: (1) all competing vegetation removed by rototilling, (2) grasses killed by spraying with dalapon 1 month before seeding, and (3) untreated blue grama sod. Furrows 1 to 2 inches deep were made by hand in each seedbed. Ten seeds per foot of row were distributed, and covered with about 0.5 inch of soil. The number of seedlings per foot of row from seedings made July 1965 with 2-year-old seeds from Lamy, New Mexico, by seedbed preparation, was:

	1965		1966	1967
Seedbed	August	November	October	October
Rototilled	2.1	1.2	0.9	0.9
Sprayed	1.8	1.3	.9	.8
Unprepared	1.4	.2	.1	.1

Table 16.--Average heights of 1-year-old fourwing saltbush plants grown in soils taken from beneath grass, shrubs, or juniper trees at four sites in New Mexico

Soil site and location sampled	Plant height					
	Source of seed					Average
	Canjilon, New Mexico	Lamy, New Mexico	Rowe, New Mexico	Keams, Arizona	Delta, Colorado	
	- - - - - - - - - - Inches - - - - - - - - - -					
Santa Fe:						
Beneath grass	17.1	15.3	14.4	10.0	14.3	14.2
Beneath shrubs	16.5	17.3	16.4	14.2	15.9	16.1
Corona:						
Beneath grass	6.4	9.9	15.0	7.7	7.0	9.2
Beneath junipers	8.9	8.1	10.3	13.1	7.9	9.7
Rio Puerco:						
Beneath grass	5.8	8.2	7.1	5.6	([1])	6.7
Magdalena:						
Beneath shrubs	10.2	12.7	14.1	9.0	8.8	11.0

[1]Plants died.

Figure 18.--Plants grown from three sources of seed in different soils (CERC = soil from beneath cercocarpus, Santa Fe; COR = soil from Corona; MAG = soil from Magdalena; RP = soil from Rio Puerco; G = grassland soil; W = woodland soil).

Initial seedling establishment was high for all three kinds of seedbeds, but most seedlings died on the unprepared seedbed, apparently as a result of competition for moisture from blue grama roots. By contrast, seedling survival was good where blue grama competition was removed either chemically or mechanically. Survival in these shallow furrows was nearly as high as in pits and basins (number of seedlings per foot of row):

	1965 August	1966 October	1967 October
Handmade pits (4 inches deep)	2.6	1.2	1.0
Handmade basins (6 inches deep)	3.4	1.0	.9

The pits and basins of Monica were made and seeded at the same time as the furrows. Moreover, the same seed source and seeding rates were used, so the results are comparable. Although seedling establishment was appreciably higher in pits and basins 1 month after seeding, survival 2 years later was only slightly greater than in shallow furrows.

Similar results were obtained at the QRA site. Seedings were made in July 1966 in furrows 1 to 2 inches deep on sites prepared three ways. Counts (number of seedlings per foot of row) in 1966 and 1967 showed the following:

	1966 October	1967 March	1967 August
Vegetation scalped	0.42	0.19	0.08
U-shaped basin (5 inches deep)	1.58	.86	.47
Enclosed basin (5 inches deep)	.94	.75	.42

Runoff water flowed into the U-shaped basin, whereas only rain water accumulated in the enclosed basin. Higher establishment in the basins is attributed to extra moisture collected and held.

Depth to Seed

Experience indicates that planting the seeds too deeply could be responsible for a number of seeding failures. Seedings failed in 2 consecutive years at a site with coarse-textured soil in central New Mexico. Few seedlings emerged despite favorable precipitation. In both years, de-winged seeds were sown in furrows 3 to 5 inches deep. Seeds were covered with only 1 inch of soil in the seeding operation, but the seeds became covered with 2 to 3 inches of soil that sloughed off the sides of the furrows.

In depth-of-seeding studies, seeds were planted at depths of 0.5, 1, 1.5, and 2 inches in sandy loam and clay loam soils (fig. 19). Moisture was held

Figure 19.--Depth-of-seeding test.

Rows of different depths were planted with 100 seeds.

Seedling emergence in sandy loam soil at the end of 30 days.

near field capacity throughout the study. Seedling emergence was significantly greater from 0.5 inch than from 1.5 or 2 inches (table 17). Seedlings also emerged more rapidly from the shallow seeding (fig. 20). Essentially the same number of seedlings emerged from the sandy loam and clay loam soils, though the trend was toward more seedlings from the greater depths in the clay loam soil.

The results indicate de-winged seeds should not be planted more than 1 inch deep. Regardless of method of seeding, precautions should be taken where there is danger of soil sloughing from the sides of furrows, or of additional soil being washed or blown in over the seeds.

Although seedling emergence was practically the same in the sandy loam as in the clay loam soil, soil texture could be a consideration in depth of seeding. Optimum depth probably would be greater in a sandy soil than in a clay soil under range conditions, where available moisture fluctuates from day to day.

Seeding depths of 0.5 to 1 inch are suggested for de-winged seeds. Cassady (1937a) reported greatest seedling emergence from seeding depths of 0 and 0.5 inch for winged seeds. Wilson (1928) recommended 0.25- to 1.5-inch seeding depths for winged seeds.

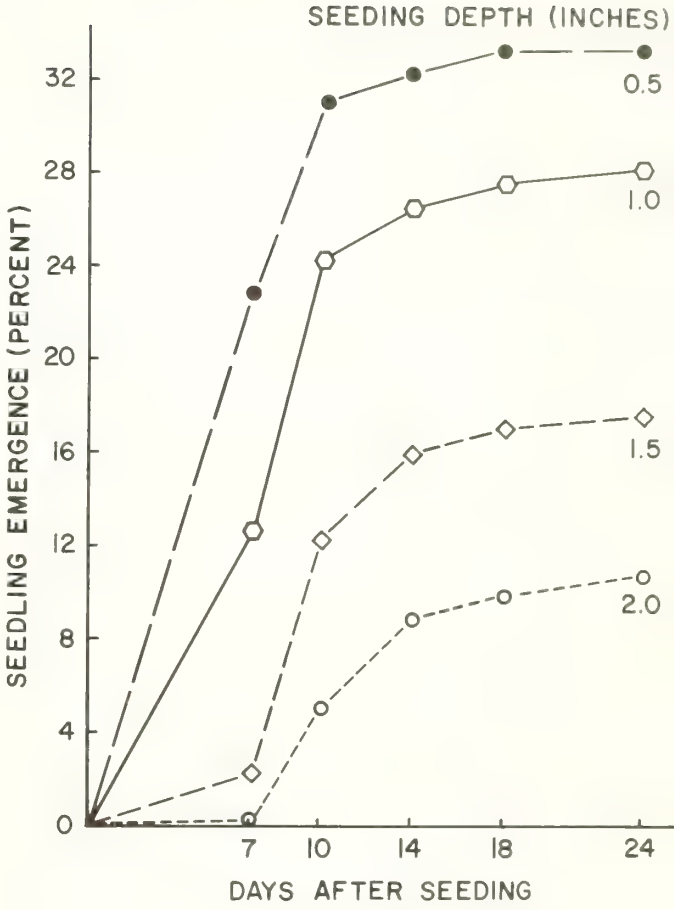


Figure 20.--Rate of seedling emergence from four depths of seeding.

Table 17.--Average percent emergence of four-wing saltbush seedlings from four depths of seeding

Soil type and treatment	Seedling emergence by planting depth			
	0.5 inch	1 inch	1.5 inches	2 inches
	- - - Percent - - -			
Sandy loam				
Packed	34.7	27.5	10.0	4.0
Not packed	38.3	29.7	16.7	16.7
Clay loam				
Packed	25.7	31.3	25.7	13.7
Not packed	36.0	26.7	19.0	9.3
Average[1]	33.7a	28.4ab	17.8bc	10.9c

[1]Values followed by the same letter do not differ significantly at the 0.05 level.

Mulches

Mulching usually has improved seedling establishment. At the Corona site, for example, seedling establishment 3 months after seeding averaged higher where a light layer of grass mulch was placed over the seeded rows (table 18). Survival 2 and 4 years later also was higher in the mulched rows. Results of the various packing treatments compared in this study, however, were inconclusive. In a similar study, also made at the Corona site in August 1965, when the soil was moist, mulching appeared particularly beneficial where soil was

packed over the seeds. The number of seedlings per foot of row was:

	November		
	1965	1966	1967
	- - (Number) - -		
Packed			
Mulched	1.7	0.9	0.8
Not mulched	1.5	.6	.4
Not packed			
Mulched	.6	.2	.2
Not mulched	.6	.2	.2

Packing probably resulted in better contact between moist soil and the seeds, and the layer of grass mulch protected the soil from drying. According to Cassady (1937b), emerging fourwing saltbush seedlings seem to require plant litter for protection. He suggested either allowing litter to accumulate naturally, or cutting shrubs and scattering them over seedings.

Rather comprehensive mulching studies were conducted at the Santa Fe Lab and the QRA site in 1967 and 1968. The objective of these studies was to test the concept of seeding in moist soil, then applying a mulch to delay moisture losses so as to improve seedling establishment. In both years, the Santa Fe Lab studies were started in July and the QRA studies in August. Seeds were planted in furrows 2 to 3 inches deep and 10 feet long. Seeding rate was 15 viable seeds per foot of row. Seeds were covered with 0.5 inch of soil. Mulches were applied immediately after seeding (fig. 21). Included as mulches were oat straw, aluminized asphalt, [7] white petroleum resin,[7] and Soil Gard. [8] Soil moisture was determined at 1- to 3-day intervals by gravimetric sampling. Soil temperatures were measured by thermistors placed in the test rows at the same level as the seeds and covered with the same amount of soil and mulch material.

In the 1967 study at Santa Fe, seeds were planted and mulches applied July 10, 1967. Seedlings began emerging July 18, emerged rapidly from July 21 to 24, and reached maximum stands

[7] *Experimental products supplied by Dr. R. L. Fern, Chevron Research, Richmond, California. Aluminized asphalt identified as 64R-1101; white petroleum resin, 68R-5268.*

[8] *A latex compound manufactured by Alco Chemical Corp., Philadelphia, Pa.*

Table 18.--Survival of fourwing saltbush seedlings at the Corona site in November 1964, 1966, and 1968; seeds from two sources were planted in July 1964

Seedbed treatment	Seedling survival by seed source					
	Taos seed			Lamy seed		
	1964	1966	1968	1964	1966	1968
	- - - Number per foot of row - - -					
Packed before seeding:						
No mulch	0.3	0.3	0.3	0.7	1.0	1.0
Mulch	1.3	.7	.7	3.7	1.7	1.3
Packed after seeding:						
No mulch	1.3	0	0	1.0	1.0	1.0
Mulch	1.3	.7	.7	1.0	1.3	1.0
Packed before and after seeding:						
No mulch	.3	0	0	1.0	.7	.3
Mulch	.7	.7	.7	1.3	1.0	.7
Average						
No mulch	.6	.1	.1	.9	.9	.8
Mulch	1.1	.7	.7	2.0	1.3	1.0

Figure 21.--
1968 Santa Fe Mulch Study.
Immediately after seeds were planted in 10-foot-long rows, mulches were applied.

Soil temperatures were measured with thermistors. Row at right is mulched with white petroleum resin.

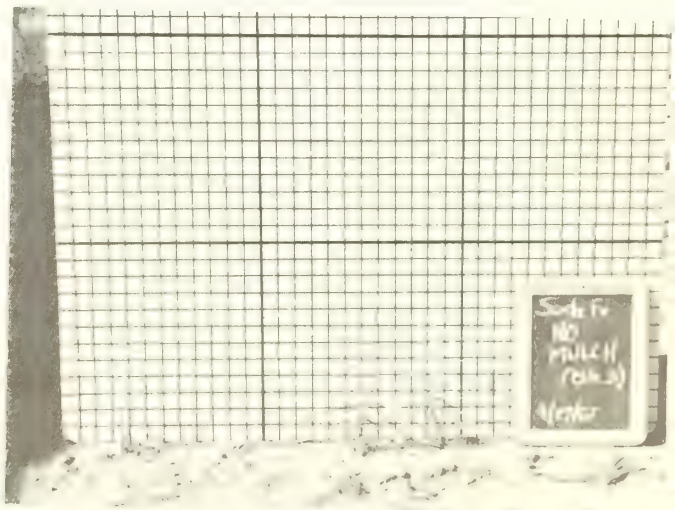
August 28. The number of seedlings per foot of row under straw and asphalt mulches was:

	Mulch treatment		
	Straw	Aluminized asphalt	None (control)
	(Number of seedlings)		
Seedlings counted:			
July 18	0.8	0.1	0.1
July 21	1.4	.8	.3
July 24	2.5	1.0	.4
July 28	2.7	1.0	.5
August 7	3.4	1.0	.5
August 14	3.5	1.1	.6
August 18	3.5	2.3	.7
August 28	3.6	2.7	.7
September 5	3.4	2.6	.7

Seedling establishment was best in rows mulched with straw (fig. 22), and rows mulched with aluminized asphalt produced stands substantially better than unmulched rows. Moisture in the top inch of soil fluctuated with rainfall (fig. 23). Unmulched soil generally was drier than mulched soil the first 2 weeks, when seedlings were emerging. None of the mulches was completely effective in preventing losses of soil moisture, but mulched soil was more moist than unmulched soil 3 to 4 days after seeding, and again 8 to 11 days after seeding. Soil temperatures were lower under the straw than under the other mulches (table 19), which helps explain the better seedling emergence in rows mulched with straw.

In the 1967 QRA mulch study, seeds were planted and mulches applied August 10. Seedling emergence was good (more than one plant per foot of row) for all treatments, largely because of 2 weeks of cool, wet weather after the date of seeding. Soil moisture was adequate for good seedling emergence even in the unmulched rows.

Figure 22.--Seedlings established in 1967 Santa Fe Mulch Study. Best establishment was in rows mulched with straw.



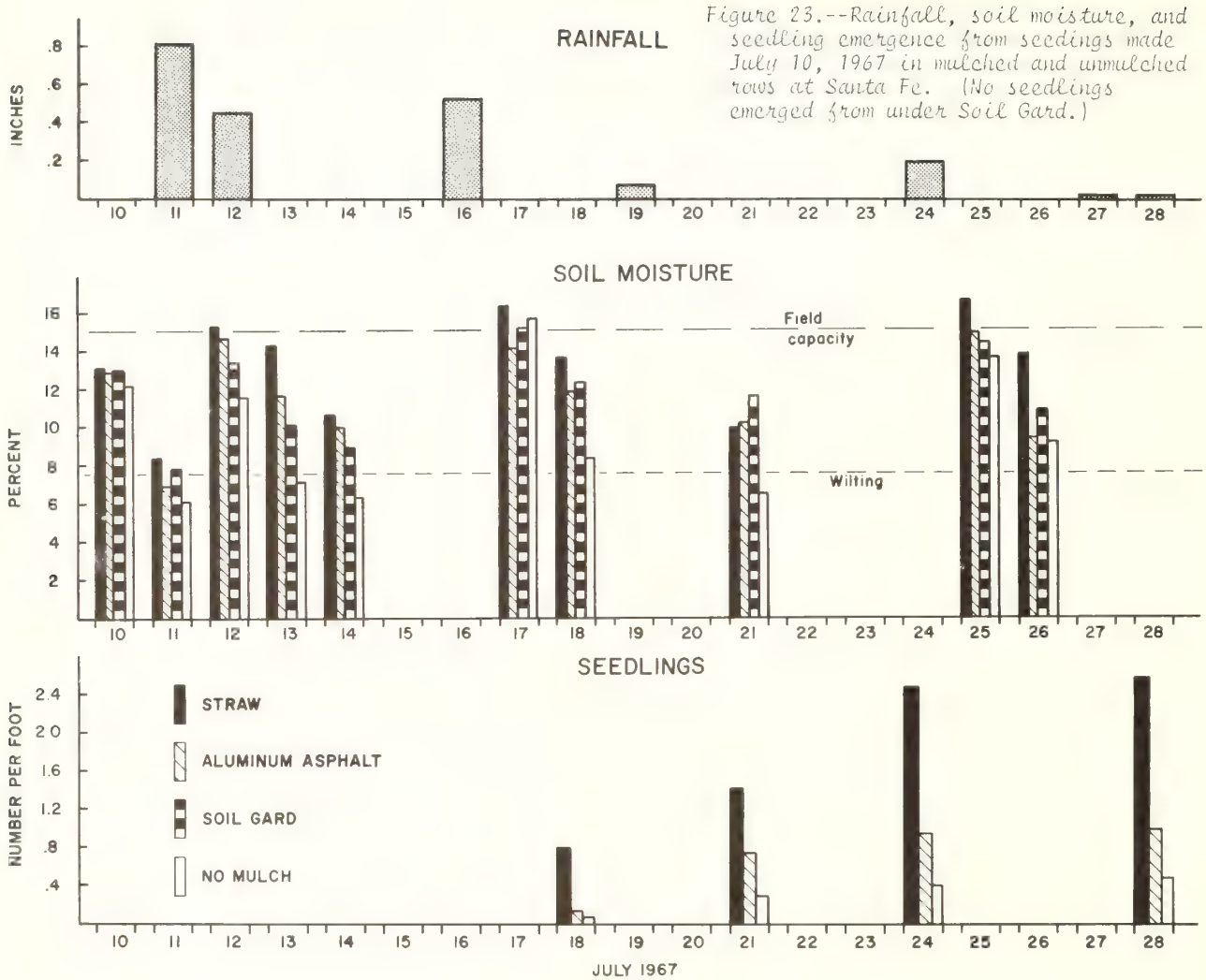


Figure 23.--Rainfall, soil moisture, and seedling emergence from seedings made July 10, 1967 in mulched and unmulched rows at Santa Fe. (No seedlings emerged from under Soil Gard.)

Table 19.--Representative soil temperatures under different mulches at the 0.5-inch depth during the first 2 weeks following seeding and mulching at the Santa Fe Lab site on July 10, 1967

Air temperature in shade (°F.)	Soil temperature (°F.) under each mulch			
	No mulch (Control)	Straw	Aluminized asphalt	Soil Gard
54	57	64	62	59
60	60	63	62	62
66	68	68	71	67
70	87	72	86	95
79	92	79	95	105
86	104	83	100	111
90	112	87	107	113
92	119	87	109	114

Effective rains fell August 11, 15, and 21. More than twice as many seedlings emerged in rows mulched with Soil Gard as in unmulched rows (table 20). The better seedling emergence is attributed to slightly higher soil moisture under Soil Gard.

The 1968 Santa Fe Lab mulch study was begun July 9. Because rainfall was negligible during the first 9 days, the various mulches were well tested. Losses in soil moisture were less under the mulches than in the unmulched rows (fig. 24). Seedlings began emerging the 6th day after seeding. Stands that emerged in rows mulched with straw or white petroleum resin were significantly better than those in other rows. Temperatures during the first week were much cooler, particularly from 10 a.m. to 6 p.m., under the straw and white petroleum resin (table 21). These cooler temperatures, together with favorable soil moisture, help explain why seed-

Table 20.--Emergence and survival of fourwing saltbush seedlings, in relation to mulch treatments at QRA site, August 10, 1967

Date of observation	Seedling survival by mulch treatment			
	No mulch (Control)	Native grass[1]	Aluminized asphalt	Soil Gard[2]
	- - - - - - Number - - - - - -			
1967:				
August 21	2.3	3.6	2.6	5.9
August 28	2.2	2.4	2.8	6.1
September 11	2.4	2.0	2.7	5.6
October 13	2.7	1.4	2.8	5.6
1968:				
May 9	2.4	1.1	2.8	4.9
October 28	2.4	1.1	3.0	4.4

[1]Application probably too heavy.
[2]Latex compound applied 1 part chemical to 4 parts water.

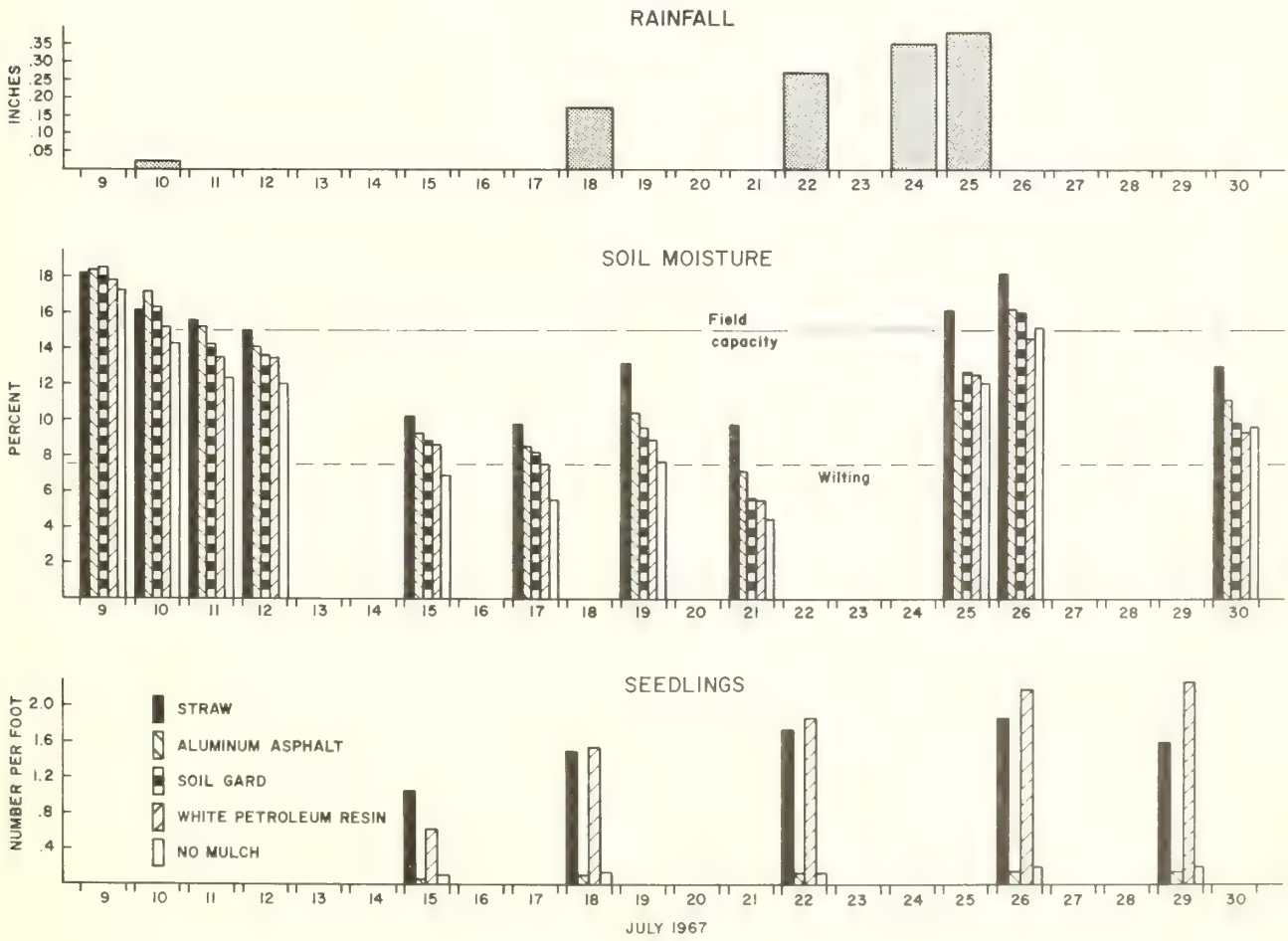


Figure 24.--Rainfall, soil moisture, and seedling emergence from seedings made July 7, 1967, in mulched and unmulched rows at Santa Fe. [No seedlings emerged from under Soil Gard.]

Table 21.--Average soil temperatures under different mulches during the first week after seeding and mulching at the Santa Fe Lab site on July 9, 1968

Time of day (2-hour periods)	Air temperature	Soil temperature by mulch treatment				
		No mulch (Control)	Straw	Aluminized asphalt	White petroleum resin	Soil Gard
	- - - - - - - - - - °F. - - - - - - - - - -					
8 to 10 a.m.	66.5	65.3	64.1	67.1	60.6	66.1
10 to 12 noon	71.1	78.0	69.5	88.8	67.4	84.8
12 to 2 p.m.	79.2	91.6	77.7	92.5	74.6	97.6
2 to 4 p.m.	84.2	103.1	82.6	100.2	80.0	107.6
4 to 6 p.m.	80.8	85.7	76.7	86.3	72.1	91.2
6 to 8 p.m.	72.4	80.1	75.8	81.5	69.4	82.1
8 to 10 p.m.	64.6	73.8	72.8	76.0	65.5	75.2
10 to 12 midnight	60.2	67.7	69.0	72.5	61.6	69.6
12 to 2 a.m.	60.2	65.6	66.6	69.1	60.6	66.8
2 to 4 a.m.	60.4	63.7	65.0	67.5	59.1	65.0
4 to 6 a.m.	62.3	63.5	64.1	67.4	59.0	64.8
6 to 8 a.m.	62.7	63.3	63.9	66.6	58.8	64.6

ling emergence was higher where straw or white petroleum resin were applied. By contrast, temperatures exceeding 100° were recorded from 2 to 4 p.m. at the seed zone in unmulched rows and in rows mulched with Soil Gard or aluminized asphalt.

The 1968 QRA mulch study was installed August 14. By August 23, seedlings had emerged in rows mulched with either straw, aluminized asphalt, or white petroleum resin (table 22). This emergence resulted from moisture in the soil at the time of seeding. Effective rains fell August 20, 26, and 28. As a consequence, seedlings emerged in all test rows. Peak numbers were reached on September 12, after which stands declined. Differences in temperature, as well as soil moisture, under the various mulches account for the differences in seedling emergence. Soil temperatures the 5th day after seeding, when all mulches were intact and functioning, show a wide spread among the different mulch treatments during the afternoon hours (fig. 25). At 3 p.m., for example, the temperature

Table 22.--Emergence and survival of fourwing saltbush seedlings in relation to mulch treatments at QRA site, August 14, 1968

Date of observation, 1968	Seedling emergence and survival by mulch treatment				
	No mulch (Control)	Straw	Aluminized asphalt	White petroleum resin	Soil Gard
	- - - - - Number per foot of row - - - - -				
August 23	0.17	5.78	4.69	2.08	0.03
August 27	.14	6.25	5.28	2.22	.03
September 3	4.75	7.44	5.97	5.64	3.14
September 12	5.00	7.31	6.06	5.83	3.22
October 7	3.22	6.00	5.56	4.61	1.58
October 28	3.06	5.75	5.47	4.50	1.58

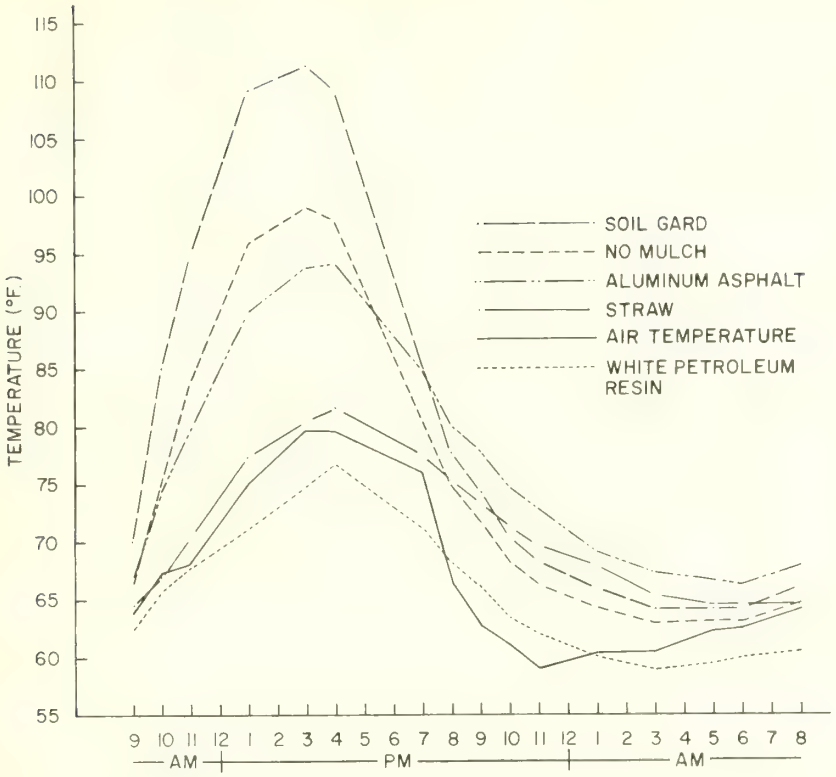


Figure 25.--Soil temperatures August 19-20 in the seed zone (0.5 inch deep) under different mulches at the QRA site. Seeds planted and mulches applied August 14, 1968.

under Soil Gard measured 111° compared with only 75° under white petroleum resin and 80° under straw. All of the mulches, except Soil Gard, lowered the soil temperature to less than that of unmulched soil from 1 to 4 p.m. During the first 5 days after seeding, soil moisture dropped sharply (fig. 26). Soil moisture exceeded field capacity in all rows at the time of seeding, yet by the 5th day, moisture was only 5 percent in unmulched rows as against 7.4 percent in rows mulched with straw. Soil moisture remained in excess of 7 percent under the aluminized asphalt from the date of seeding to September 3, which undoubtedly explains the good seedling emergence for this mulch. Moisture under straw likewise remained higher than for the other treatments throughout the first 2 weeks. None of the mulches, however, was fully effective in preventing moisture losses from the top inch of soil.

Results of these mulch studies support the concept of seeding when the soil is moist, and delaying moisture losses by applying mulch over the seeded rows. If mulches are used to improve chances of success from summer seeding, the mulch material should function to reduce afternoon soil temperatures, such as straw and white petroleum resin did in our studies. Otherwise the mulch material, like Soil Gard, may cause the top layers of soil to heat up to temperatures that inhibit germination. This characteristic of certain mulches to raise the soil temperature could be an advantage, however, for seeding during the cooler seasons. For example, the seeds might be placed in moist soil in early spring when the temperatures are low, then covered with a mulch such as Soil Gard, black asphalt, or black polyethylene. The mulch would serve the dual purposes of conserving soil moisture and raising soil temperatures.

Mechanized Trials

Seedbed preparation probably is necessary to obtain good stands of fourwing saltbush. Wilson (1928) reported failures from broadcasting the seed without seed coverage, but obtained satisfactory stands when the seeds were broadcast and then covered by disking. In 26 trials, Bridges (1941) obtained a good stand from only one. He blamed rabbits, poor seedbed preparation, and wrong time

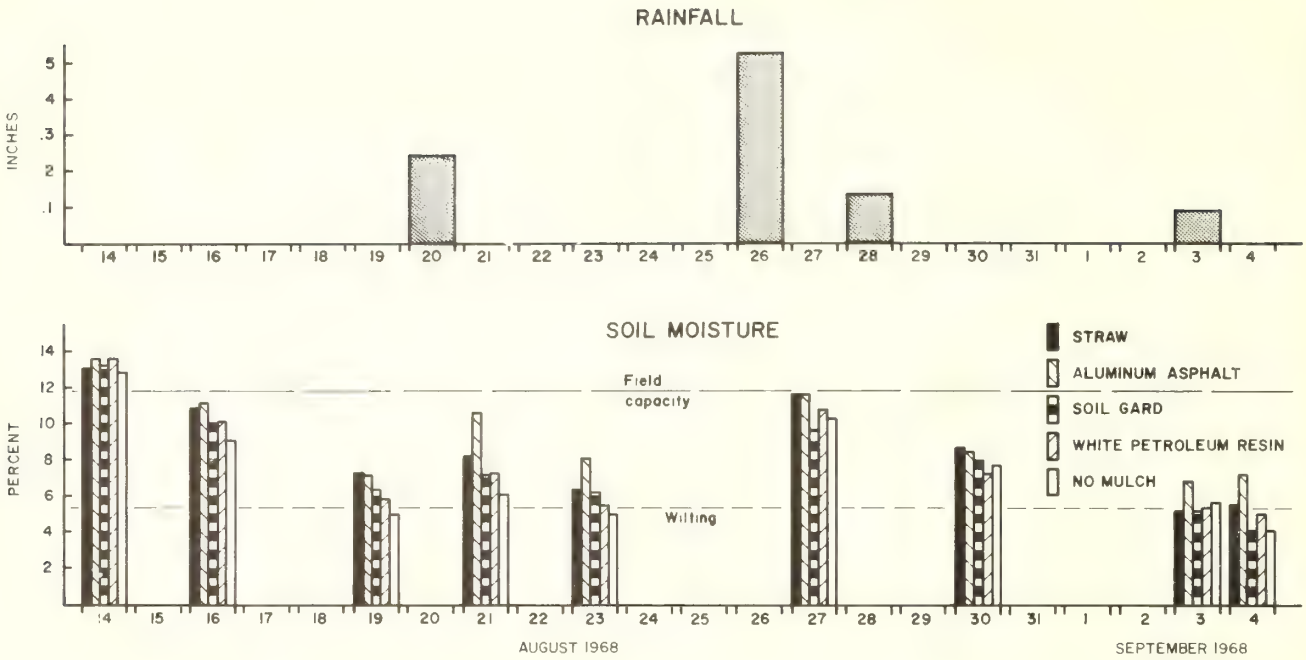


Figure 26.--Precipitation and soil moisture under mulches at the QRA site during the first 3 weeks after seeding. Seeds planted and mulches applied August 14, 1968.

of seeding for the failures. In studies at the Monica site in west-central New Mexico, plants were established by drilling into drought-weakened blue grama sod, but resulting stands were much poorer than those on prepared seedbed (Springfield 1963).

In our studies at the Monica site, methods of seeding included (1) drilling and (2) cultipacker seeding. Seedbeds were prepared by (1) plowing, (2) pitting, (3) plowing and pitting, and (4) no cultural treatment (fig. 27). Rate of seeding was 20 pounds of de-winged seed per acre, or about six viable seeds per square foot.

Emergence (number of seedlings per square foot) 2 months after seeding varied according to method of seedbed preparation and seeding:

Seedbed preparation	Grain drill	Cultipacker-seeder
	(Number of seedlings)	
None	0.22	0.12
Pitted	.55	.70
Plowed	.68	1.38
Plowed-pitted	.58	1.12

Significantly fewer seedlings emerged on the unprepared seedbed; other differences were not significant. The trend, however, was toward more seedlings wherever the cultipacker-seeder was used on loose seedbeds.

Eleven years after the plots were seeded, significantly more plants were still present on prepared than on unprepared seedbeds (fig. 28). No differences in number of plants were measured, however, among pitted, plowed, or plowed-pitted seedbed. Comparisons of the two seeding methods indicated better stands with cultipacker seeding on plowed seedbeds. Beneficial effects of cultipacker-seeding were especially noticeable on plowed-pitted seedbeds.

Less than half the seedlings present the year of seeding survived as mature plants 11 years later:

Preparation	Average survival (Percent)
Pitted	41
Plowed	30
Plowed-pitted	35

Figure 27.--Two methods of seeding were compared on four kinds of seedbeds at the Monica site where fourwing saltbush seeds were planted June 1951.

Cultipacker seeder on plowed-pitted seedbed.

Drilling on unprepared seedbed (pitted seedbed in foreground).

Figure 28.--Fourwing saltbush plants were evaluated in August 1962, 11 years after planting on the Monica site. More plants had become established on prepared than unprepared seedbeds.

Plowed.

Unprepared.

Average heights and diameters of plants in the 11-year-old stands were about the same, regardless of the method of seedbed preparation and seeding. Crown cover, however, was substantially higher on prepared seedbeds than on the unprepared seedbeds.

Of three methods of seedbed preparation tested, none proved definitely superior. Where there is a remnant of desirable species, pitting or furrowing may be preferable, but where the native cover is composed mainly of undesirable plants, plowing probably would be best.

Although seedbed preparation appears necessary for the establishment of good stands, the seeding of fourwing saltbush on unprepared seedbeds could be feasible under certain conditions. For example, many ranges in the Southwest support a satisfactory cover of herbaceous plants but no browse. On such ranges, drilling into the undisturbed herbaceous cover, particularly if it is weakened due to drought as in the Monica study, might result in a fair stand of browse.

Transplanting

Cassady and Glendening (1940) recommended transplanting fourwing saltbush seedlings during the rainy season. Plummer et al. (1966) reported seedlings, nursery stock, or wildlings can be transplanted easily early in the spring. Burnham and Johnson (1950), however, reported their attempts to transplant seedlings to the field in northeastern New Mexico have been discouraging. McMillan (1960) considered transplanting feasible where only a few plants are wanted; he recommended seeding as more practical for range rehabilitation in the semiarid parts of California.

In our studies, growth of plants differed according to source of seed. At the Wingate site, for example, transplants from certain sources of seed planted in August 1966 grew taller than other sources. All plants were 12 inches tall when transplanted. Differences in height as of October 18, 1968 are due to growth or "die back":

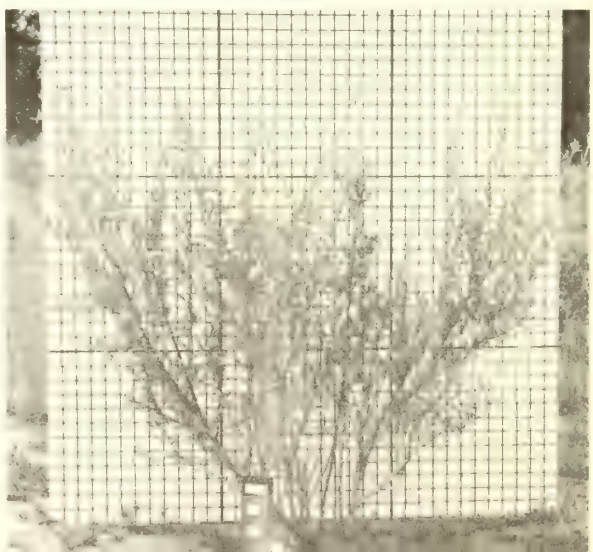
Seed source	Average height (Inches)
Lamy, New Mexico	17.8
Corona, New Mexico	16.2
Delta, Colorado	15.3
Gran Quivira, New Mexico	14.6
Isleta, New Mexico	14.4
Keams Canyon, Arizona	12.6
Datil, New Mexico	12.2
Lovington, New Mexico	10.2
Lordsburg, New Mexico	8.4
Safford, Arizona	8.1
Ft. Thomas, Arizona	7.8

Bare-root stock may be successfully established if soil moisture is adequate (fig. 29). One-year-old

Figure 29.--Bare-root stock may be successfully established if soil moisture is adequate:

6 months after transplanting.

2.5 years after transplanting.



plants from the Los Lunas Plant Materials Center were planted as bare-root stock at the Corona site in April 1962. Soil moisture was near field capacity, and temperatures were cool at the time of planting. Percent survival was higher where competing blue grama was eliminated:

	Survival	
	Grass competition	No competition
	(Percent)	
1963	75	88
1964	62	82
1965	56	68
1966	44	68

Decreases in percent survival reflect changes in site conditions and rabbit and deer browsing. Competition from grass gradually increased on all areas, particularly on the "no competition" areas, as no measures were taken to control grass that became reestablished.

Survival from transplants in our New Mexico studies has been high at all sites. Except where rabbits or rodents destroyed plants, survival 2 and 3 years after planting has ranged from 50 to 100 percent.

Survival has varied according to age and size of seedlings. Seedlings planted in August 1964 at the QRA site in competition with native blue grama showed the following survival and growth in September 1967:

When transplanted		September 1967	
Age (Weeks)	Average height (Inches)	Survival (Percent)	Average height (Inches)
4	2.7	55	8.8
8	6.3	100	10.7
14	11.9	100	15.5

Apparently, seedlings should be at least 8 weeks old and 6 inches tall for transplanting.

Vigor and growth of transplants appear to vary with kind of site preparation. Seedlings 5 to 6 inches tall transplanted in July 1966 measured as follows in March 1967:

	Average height (Inches)
No site preparation	7.8
Shallow furrows	7.8
Large pits (5 inches deep)	12.5
Plastic mulch squares	14.0

Plants grew best on sites prepared by methods that eliminate much of the competing vegetation and provide additional moisture.

Time to Seed

Hervey (1955) reported spring seedings were more successful than fall seedings in Colorado. Plummer et al. (1966) obtained the best stands in Utah from winter planting; seeds were broadcast on snow and covered by chaining in late winter or early spring. According to Wilson (1928) seedlings emerge whenever the soil remains moist for several days during the fall, winter, or early spring. Bridges (1942) recommended seeding from September to January.

Our trials conducted over a 3-year period at two sites in New Mexico showed spring and midsummer seedings were more successful than early or late fall seedings (Springfield and Housley 1952). Results of these trials indicated success of seeding depends largely on the amount and seasonal distribution of precipitation during the period when temperatures are favorable for germination and establishment; these conditions prevail most consistently in spring and midsummer in New Mexico.

Other studies conducted for 3 years at the QRA site showed large differences in seedling establishment from year to year and from season to season (table 23). In general, precipitation patterns explain the differences in stands resulting from the nine dates of seeding.

The October 16, 1964 seeding produced a stand of about one plant per 5 feet of row. Since no seedlings were found in late April, the seedlings must have emerged in May or June. Precipitation for the May-June period totaled 3.80 inches, well above average for the area. This precipitation explains the development of seedling stands from the April 28, 1965 seeding as well as for the October 16, 1964 seeding. The July 1, 1965 seeding was slow in developing. No seedlings were

Table 23.--Emergence and survival of fourwing saltbush seedlings from nine dates of seeding at the QRA site, 1964-67

Date of seeding	Seedlings			Precipitation		
	Maximum emergence		Survival on October 28, 1968	Between dates of seeding	1 month after seeding	2 months after seeding
	Date	Number per foot of row		- - - Inches - - -		
1964:						
October 16	July 1, 1965	0.22	0.17	3.82	([1])	([1])
1965:						
April 28	July 1, 1965	.56	.50	3.80	1.52	3.80
July 1	September 15, 1965	.50	.33	5.89	1.04	2.67
September 29	November 2, 1965	1.33	0	5.14	2.35	([1])
1966:						
March 30	--	0	0	2.17	.19	1.12
July 1	--	0	0	6.77	1.38	4.49
October 11	March 17, 1967	3.38	1.11	2.08	([1])	([1])
1967:						
April 6	August 18, 1967	2.67	.39	3.26	.04	1.11
July 18	August 18, 1967	4.89	1.94	[2]4.43	3.18	3.81

[1]Insufficient data.
[2]To October 13, 1967.

visible August 18, but a fair stand of very small, newly emerged seedlings was found September 15. These seedlings, only 1 inch tall, were present November 2, 1965, but by June 1966, about 20 percent of them had died.

No seedlings became established from three dates of seeding: September 29, 1965, March 30, 1966, and July 1, 1966. Seedlings emerged from the September 29, 1965 seeding when 2.35 inches of precipitation fell during the month of October, but none of these seedlings survived through winter. No emergence was ever observed for the March 30 and July 1, 1966 seedings, despite what seemed to be relatively favorable moisture conditions. Presumably the intervals between effective rains were such that germination was initiated and the seedlings began developing but died before they emerged.

By contrast, the three most recent dates of seeding—October 11, 1966, April 6, 1967, and July 18, 1967—resulted in excellent seedling emergence. The 6 months following the October 11, 1966 seeding were unusually dry—only 2.08 inches precipitation at the study site. Examination of weather records at the Santa Fe Airport, 4 miles from the study site, showed 1.05 inches fell in March, 0.43 on March 20, just 10 days before seedlings were observed emerging. Though the top 0.5 inch of soil was dry March 30, excavation revealed the seedlings were rooted in moist soil. Nearly two-thirds of these seedlings died during the next 2 months when precipitation totaled only 1.11 inches. Counts made March 30, 1967 showed 3.4 seedlings per foot compared with 1.3 per foot on June 27, 1967. Most of the seedlings alive in late June 1967 survived through October 1968. The July 18, 1967 seedings were benefited by abundant, well-spaced rains; seedling emergence and establishment were exceptionally high.

April and July seedings were far more successful than October seedings at the Monica site (table 24). Seedings with seeds collected at Taos and at Lamy were made on sites prepared three ways in blue grama sod. The number of seedlings found in October 1967 reflects the combined effects of delayed emergence and seedling mortality. Delay in seedling emergence was especially apparent on plots seeded in October 1964. Seedling mortality averaged about 50 percent for the April and July seedings. Seedling establishment averaged highest from seeding in April for the Taos seed, but from seeding in July for the Lamy seed. Perhaps the

Table 24.--Establishment of fourwing saltbush seedlings in relation to three seeding dates at the Monica site (seed collected at Taos and Lamy)

Date of observation	Precipitation during interval	Seedling establishment[1] by time of seeding and seed source					
		October 12, 1964		April 1, 1965		July 7, 1965	
		Taos	Lamy	Taos	Lamy	Taos	Lamy
	Inches	- - - - Number per foot of row - - - -					
1965:							
April 1	1.58	0	0	--	--	--	--
August 10	8.68	0	0	0.9	1.3	0.4	1.9
November 17	4.44	0	.1	.6	.8	.2	1.2
1966:							
August 26	9.37	.1	.4	.4	.8	.2	1.0
October 18	2.12	.1	.3	.4	.8	.2	.9
October 23	12.44	.1	.2	.4	.6	.2	.9

[1]Average for rototilled and chemically sprayed seedbeds.

Taos seed, which originated from a more northerly area, responds better to cool temperatures than the Lamy seed.

Precipitation is more dependable during the period July 12 to August 23 for most areas in New Mexico.

Seeding Rate

Rate of seeding will depend on the size and quality of the seed. Various seeding rates have been recommended. Wilson (1928) recommended 8 to 10 pounds per acre for winged seeds. Later he recommended 14 to 16 pounds per acre (Wilson 1931). Van Dersal (1938) also recommended 14 to 16 pounds per acre. Bridges (1942) suggested 10 to 15 pounds, and the U. S. Forest Service (1948), 8 to 10 pounds per acre. Springfield and Housley (1952) recommended three viable seeds per square foot. Plummer et al. (1966) reported good stands from spot seeding by hand at the rate of 5 pounds per acre.

Based on recent findings concerning seed fill and number of seeds per pound, seeding rates of 4 to 8 pounds per acre for de-winged seed or 8 to 15 pounds per acre for winged seed should be adequate.

Adaptability

Fourwing saltbush survived and grew for 16 years at five representative pinyon-juniper sites in New Mexico (Springfield 1965). Plots seeded in 1946 were evaluated periodically until 1962. Stand ratings in 1962 for two sources or geographic strains were as follows:

	Rating	
Study site	Las Cruces source	Taos source
Corona	Fair	Fair
Fort Bayard	Poor	Good
Glorieta Mesa	--	Good
Monica	Excellent	Excellent
Taos Junction	Poor	Good

At the Corona site, the stands were damaged by rodents and deer.

Stands produced from seed collected near Taos generally rated higher than stands from seed collected near Las Cruces (fig. 30). Adaptability ratings of 14-year-old stands at Tres Piedras and Costilla in New Mexico indicate that probably 8,500 feet represents the upper elevational limit of adaptability.

Figure 30.--These fourwing saltbush plants at the Monica site were established by planting seed from near Taos in 1946. These 14-year-old plants have withstood the rigors of the climate and are considered well adapted. Plants from seed collected near Taos generally have proved adapted to more sites than plants from seed collected near Las Cruces.

More recently, container-grown plants have been planted at the various sites to test their adaptability to different climates and soils. The plants were grown from seed collected at a number of sites in Arizona and New Mexico. Plants were 1 year old at the time of transplanting.

Though the plants have been tested only a few years, indications are that certain geographic sources, which may or may not represent distinct ecotype strains, are better adapted to a given area. For example, plants from Chevelon, Arizona, were definitely taller and more vigorous than plants from other sources after 4 years at our QRA site:

Source	Average height (Inches)	Average vigor[1]
Arizona:		
Chevelon	26.5	2.5
Benson	11.6	1.7
New Mexico:		
Los Lunas	19.0	2.1
Moriarity	15.2	2.0
Magdalena	15.1	1.9
Datil	15.0	1.8
Corona	12.6	1.7
Bernalillo	10.7	1.6
Hatch	8.8	1.5
Glenwood	7.6	1.4

[1]1 = poor; 2 = fair; 3 = good.

Poorest in growth and vigor were the plants from Glenwood, New Mexico. Another example is provided by plants at our Silver Hill site, planted in August 1965. Of 11 ecotypic strains, these four New Mexico sources appear best adapted, based on measurements made October 25, 1968:

	Average height (Inches)	Average vigor[1]
Isleta	17.9	2.1
Gran Quivira	15.8	1.8
Deming	13.4	1.8
Placitas	9.6	1.5

[1]1 = poor; 2 = fair; 3 = good.

Wilson (1931) reported seed from Las Cruces did not give satisfactory results when planted near Galisteo, 220 miles north. But seed from Estancia, which is only 40 miles south of Galisteo, produced shrubs that grew well near Galisteo.

As a general rule, seed for revegetation should be obtained from nearby or north of the planting site.

Insect and Animal Damage

Many successful seedings of fourwing saltbush have been damaged or destroyed by insects, rabbits, or rodents. Grasshoppers eat the cotyledons and stems of small seedlings, and some seedling stands have been completely destroyed. Rabbits and rodents also can severely damage or destroy seedling stands. Wilson (1928), Cassady and Glendening (1940), Bridges (1941), and Plummer et al. (1966) stressed the importance of controlling rabbits and rodents. Both cottontails and jackrabbits are very destructive to saltbush seedlings.

Tests were made to determine the effects of grasshoppers on seedling survival at the QRA site. These tests were conducted because evidence accu-

mulated in 1965 and 1966 indicated the death of many seedlings was due to grasshoppers, not drought. In March 1967, small wire cages were installed over selected groups of seedlings, and charts were drawn showing the position of each seedling inside and outside the cages. Comparisons between charts drawn March 7 and August 7 showed the following seedling mortality:

	Percent
Open to grasshoppers	57
Protected from grasshoppers	22

Further studies were made at the QRA site to determine how much damage grasshoppers, and rodents or rabbits, do to seedlings. In July 1967, seedlings 2 to 3 inches tall were transplanted to the site. One-third of the seedlings were protected from rodents or rabbits by wire cages, and another one-third were protected from grasshoppers (fig. 31). By November 3, 1967, rodents or rabbits had damaged half of the seedlings (table 25). Cottontails were responsible for most of the damage. Grasshoppers injured a higher percentage of seedlings than did rabbits, but the degree of injury to individual seedlings was less. Thus, grasshoppers ate portions of leaves of many seedlings but the dam-

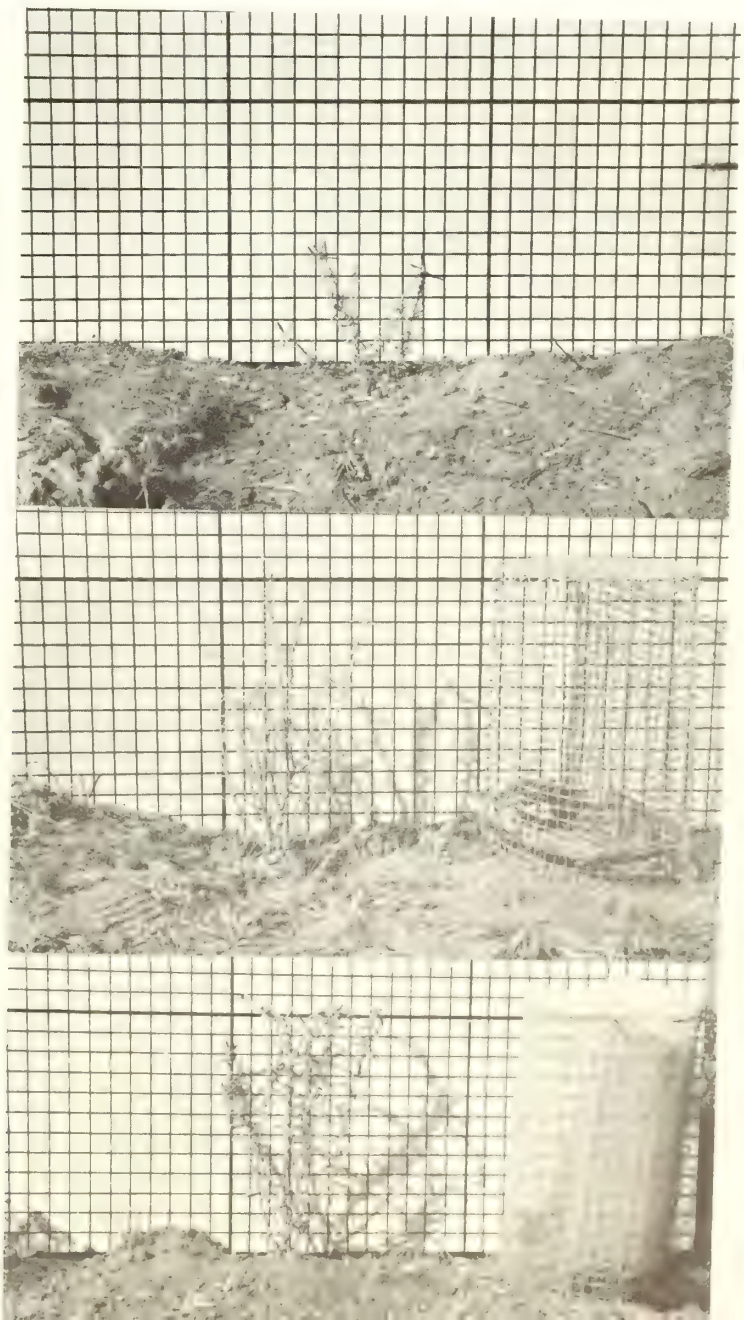


Figure 31.--Condition of fourwing saltbush plants 16 months after seedlings were transplanted to QRA site in July 1967:

Not protected (control).

Rodents and rabbits excluded.

Rodents, rabbits, and grasshoppers excluded.

Table 25.--Grasshopper, rodent, or rabbit damage to fourwing saltbush seedlings transplanted to QRA site, July 1967

Plot treatment and date observed, 1967	Plants damaged by--		Degree of damage[1]	
	Grasshoppers	Rodents, rabbits	Grasshoppers	Rodents, rabbits
	- - Percent - -			
Not protected (control):				
August 7	0	8	0	7.0
August 21	17	25	2.0	7.7
September 18	67	33	1.9	7.0
November 3	67	50	1.9	6.8
Rodents, rabbits excluded:				
August 7	8	0	2.0	0
August 21	25	0	2.0	0
September 18	92	0	1.6	0
November 3	92	0	1.6	0

[1] 1 to 2 = very light 5 to 6 = moderate
3 to 4 = light 7 to 8 = heavy

age was light. Rabbits, on the other hand, either heavily browsed a plant or completely ignored it; there was no evidence of light browsing by rabbits during the 4 months.

In 1968, grasshoppers were not numerous and inflicted practically no damage, but rabbits occasionally browsed the plants. Survival and height of the plants, as of November 4, 1968, were as follows:

	Average survival (Percent)	Average height (Inches)
Not protected (control)	67	9.9
Rodents, rabbits excluded	92	11.5
Rodents, rabbits, grasshoppers excluded	100	11.9

These results, coupled with observational evidence, indicate rodents or rabbits are more serious enemies of fourwing saltbush than are grasshoppers. When grasshoppers are numerous they may severely damage very small seedlings, especially in the cotyledon stage, but they have little effect on the growth of older seedlings. Rodents and rabbits, however, can be extremely destructive even to relatively large seedlings, although seedlings 8 to 12 inches tall seem less vulnerable.

Repellent treatment appeared partially effective in reducing rabbit browsing damage to seedlings on the QRA site. Plants 5 inches tall were planted in August 1966, and sprayed in November. Observations in March 1967 revealed plants treated with repellent (Arasan 42-S plus sticker) were taller and browsed less severely by rabbits:

	Average height (Inches)	Average browsing injury[1]
Not sprayed	4.7	1.7
Sprayed	8.7	.4

[1] 1 = low; 2 = medium; 3 = high.

Apparently the repellent remained effective through the winter months.

Browsing by deer during the winter and by rabbits throughout the year damaged 2-year-old plants at the Corona site. Spraying plants with a repellent (Arasan 42-S plus sticker) reduced the injury only slightly.

Mature plants of fourwing saltbush plants rarely are damaged by rabbits or rodents, but deer and livestock sometimes browse plants so closely that vigor is reduced. Mature plants also have been found damaged by insects. Two scale insects, one identified as the irregular wax scale (Cercoplastes irregularis Ckll.), and the other an ensign coccid (Orthezia annae Ckll.), reduce plant vigor and seed production. Galls are fairly common; one cause of these galls is a fly (Asphondylia atriplicis (Townsend)). These gall-makers in turn are para-

sitized by a wasp (Torymus capillaceous (Huber))[9]. Another insect, an unidentified case bearer, has been observed to bore into seeds and destroy the embryo.

SUMMARY AND CONCLUSIONS

Fourwing saltbush, a valuable browse plant, is palatable and nutritious the year round; it promises to play an important role in range improvement throughout the Southwest. Studies were conducted to learn more about its requirements for germination and establishment.

Size of seed varies from site to site, plant to plant, and even on the same plant. Number of seeds per pound ranged from 7,800 to 54,900 for winged seed and from 13,200 to 76,800 for de-winged seed.

Usually only about half of the seeds can be expected to contain embryos, although seed fill varies according to place and year of collection. The larger seeds within a collection generally are better filled than the smaller seeds, and some collection sites consistently produce seeds with higher fill.

Seeds are easily collected when they are ripe in the fall. Because they remain on the bushes during the winter, the seeds may be harvested over a period of several months. Hand collection is the usual practice.

The seeds apparently undergo afterripening, which seems to be essentially complete within 10 months after collection in the fall.

Winged seeds are fully imbibed in 24 hours, de-winged seeds in 15 hours.

Germination usually is best at relatively low temperatures. The optimum temperature range appears to be from 55° to 75°. At temperatures less than 55°, germination is delayed and proceeds more slowly than in the optimum range. High temperatures, especially those exceeding 80°, tend to suppress germination.

Germination is decreased and delayed by increasing moisture stress; it is negligible at stresses approximating wilting percentage. Seeds germinated well even under a relatively high 7-atm. stress at 63°, which suggests moisture stress may be less important when temperatures are near optimum.

Light apparently is neither required for germination, nor does it inhibit germination when temperatures are near optimum. There are indications, however, that light may be needed at relatively high temperatures, and perhaps also for freshly collected seeds.

The seeds appear to be sensitive to deficient aeration.

Seed viability can be maintained under ordinary dry storage; refrigeration or other special storage conditions are not necessary. Viability varies with year of collection, although some plants consistently produce seeds of higher viability than others. Seeds retain their viability for many years; seeds from one lot lost only half their germinative energy in 16 years.

Various seed treatments have not consistently improved germination. De-winging the seed in a hammermill, an accepted practice, reduces bulk, facilitates handling and seeding, and hastens germination. Effects of scarification vary with the source of seed and seedcoat characteristics; thin-coated seeds were damaged whereas thick-coated seeds were benefited by very light scarification. None of several chemicals, including thiourea, citric acid, hydrogen peroxide, and sulfuric acid, proved effective for stimulating germination. Results from stratification were inconsistent; some seeds germinated better following 30 days of moist chilling, but most did not respond. No advantages were found from soaking or washing the seeds in water.

Seed viability can be determined by staining embryos with tetrazolium chloride. This is a quick test, the results of which are available in hours rather than in weeks.

Under nursery conditions, seedlings begin emerging within 6 to 10 days after the seeds are planted, provided moisture is adequate and temperatures are near optimum. Emergence usually is complete within 12 to 20 days. Seedling mortality sometimes is high, presumably due to seedborne or soilborne organisms. Contamination of seedlings by pathogens is not uncommon. Fungicidal treatment of seeds or soil, or both, has been partially effective in reducing seedling mortality.

Growth of plants in the nursery generally has been better in soils from representative sites than in horticultural mixes.

[9] *Insects identified through cooperation with the Insect Identification and Parasite Introduction Research Branch, U. S. Dep. Agr., Agr. Res. Serv., Beltsville, Md.*

De-winged seeds should not be planted more than an inch deep. Seedling emergence was greater and more rapid from 0.5 inch than from 1.5 or 2 inches.

Mulching usually improves seedling establishment. The application of straw, certain chemical mulch materials, or native grass generally resulted in greater seedling emergence and survival. Planting the seeds in moist soil and applying a mulch to delay moisture losses appears to be an effective seeding technique. Mulches that reduced afternoon temperatures were the most satisfactory for summer seeding.

Seedbed preparation probably is necessary to obtain good stands of fourwing saltbush by direct seeding. Although plants have been successfully established by drilling directly into drought-weakened blue grama sod, the resulting stands were much poorer than those on prepared seedbeds. Plowing is undoubtedly the best method of seedbed preparation where the native cover is composed mainly of undesirable plants. Where a remnant of desirable species exists, however, pitting or furrowing may be preferable.

Transplanting is an effective method of establishing stands, particularly on critical areas. Nursery-grown plants or wildlings can be readily transplanted in moist soil. Survival is high. Plants should be at least 6 inches tall for transplanting. Removal of competing vegetation from around the plant improves survival and growth.

Spring and midsummer seedings usually are more successful than fall seedings in the Southwest. Success of seeding depends largely on the amount and seasonal distribution of precipitation during the period when temperatures are favorable for germination and establishment.

Seeding rates of 4 to 8 pounds per acre for de-winged seed or 8 to 15 pounds per acre for winged seed should be adequate.

Long-term adaptability trials showed fourwing saltbush was adapted at several sites ranging in elevation from 6,300 to 7,500 feet. Plants grown from southern New Mexico seed generally were less well adapted than those from northern New Mexico seed. Both sources grew poorly at 8,500 feet. As a rule, seed for revegetation should be obtained from nearby or north of the planting site.

Control of rabbits and rodents, where they are numerous, is recommended. Stands of fourwing saltbush are especially susceptible to damage during the seedling stage. Repellents have partially prevented damage.

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COMMON AND BOTANICAL NAMES OF PLANTS MENTIONED

Grasses

Dropseed, sand	*Sporobolus cryptandrus* (Torr.) A. Gray
Galleta	*Hilaria jamesii* (Torr.) Benth.
Grama, blue	*Bouteloua gracilis* (H.B.K.) Lag.
Grama, sideoats	*Bouteloua curtipendula* (Michx.) Torr.
Muhly, ring	*Muhlenbergia torreyi* (Kunth) Hitchc.
Wheatgrass, western	*Agropyron smithii* Rydb.

Trees and Shrubs

Creosotebush, Coville	*Larrea tridentata* (DC.) Coville
Juniper, one-seed	*Juniperus monosperma* (Engelm.) Sarg.
Mountainmahogany, true	*Cercocarpus montanus* Raf.
Pinyon	*Pinus edulis* Engelm.
Sagebrush, big	*Artemisia tridentata* Nutt.
Winterfat, common	*Eurotia lanata* (Pursh) Moq.

Springfield, H. W.
1970. Germination and establishment of fourwing saltbush in the Southwest. USDA Forest Serv. Res. Pap. RM-55, 48 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

Seeds of fourwing saltbush remain viable many years under ordinary dry storage. Usually, only about half the seeds contain embryos. Viability is easily checked with tetrazolium chloride. After-ripening is complete in 10 months. De-winging the seeds facilitates handling and hastens germination. Seeds should be planted 0.5 to 1 inch deep during spring or summer; seedbed preparation is recommended. Mulching usually improves seedling establishment. Seeds are fully imbibed within 24 hours; optimum temperatures for germination are 55°F. to 75°F. Germination is decreased and delayed by increasing moisture stress. Transplants may be used effectively for critical areas.

Key words: Germination, establishment, fourwing saltbush, Atriplex canescens

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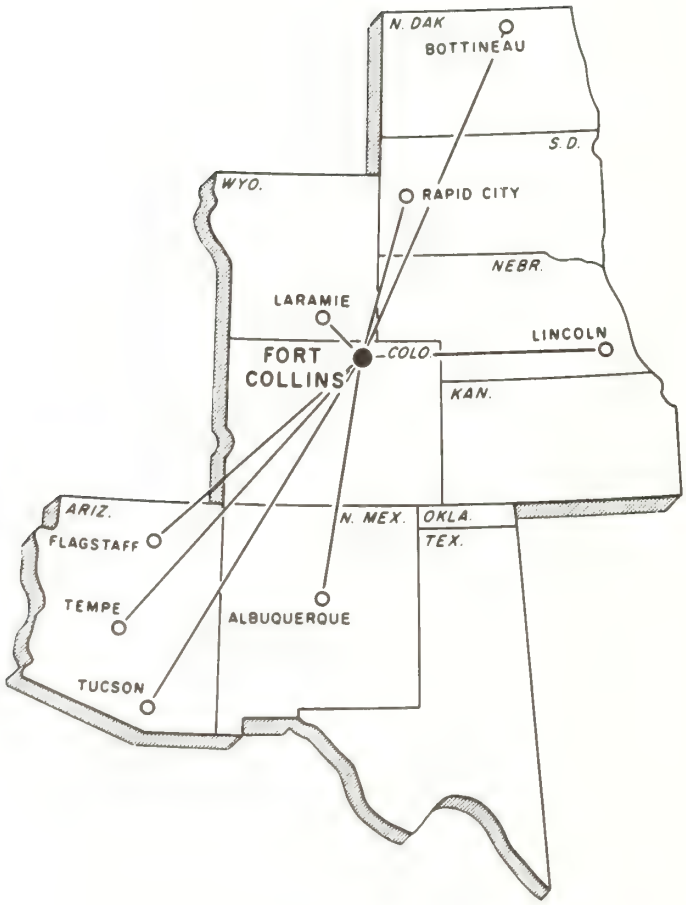
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Effects of

TREE AND SAWYER FACTORS

on costs of

FELLING LARGE ALLIGATOR JUNIPERS

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Robert L. Miller

Thomas N. Johnsen, Jr.

USDA Forest Service

Research Paper RM-56

July 1970

Rocky Mountain Forest and Range Experiment Station

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1970

Effects of Tree and Sawyer Factors on Costs of Felling Large Alligator Junipers

by

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Agricultural Research Service[2]

[1]Central headquarters maintained at Fort Collins, in cooperation with Colorado State University; research reported here was conducted at Flagstaff, in cooperation with Northern Arizona University. Miller is now with the Department of Forestry, Oklahoma State University, Stillwater.

[2]Located at Flagstaff, Arizona.

Abstract

Costs of felling large alligator juniper trees are affected by tree conditions and stem diameter. Conditions that increased felling time were: (1) no appreciable lean or imbalance; (2) low-forked trees on which a second cut was necessary to reduce stump height to meet a treatment requirement; and (3) deteriorated and split stems which required vertical cuts to fell in more than one piece. Sawyer skill and safety were important factors in felling these trees. Possible alternative practices are suggested for trees with these conditions, and for very large trees.

Functions relating felling time and felling time per unit volume to stem diameter are provided. Results can be applied in treatment design and in estimating practice and harvesting costs.

Effects of Tree and Sawyer Factors on Costs of Felling Large Alligator Junipers

Robert L. Miller and Thomas N. Johnsen, Jr.

Alternative land-management programs involving substantial investments in removing alligator juniper (Juniperus deppeana Steud.) are underway in the Southwest. Large-scale clearing for forage improvement is currently practiced, and removal to increase water production is being studied. The potential exists for increased utilization of juniper in a variety of products.[3] Information is therefore needed on methods, costs, and means for reducing costs of felling junipers. This study reports the effects of tree characteristics, working conditions, and sawyer factors on felling time, and suggests alternatives that can be adopted to improve operational efficiency.

The data were taken during the treatment of a 100-acre experimental alligator juniper watershed within the Beaver Creek Pilot Watershed (Worley 1965) in central Arizona. The watershed was converted to herbaceous cover as part of a water-yield experiment.

Methods

The study was planned to obtain data on felling times and tree characteristics for as many large trees as possible. Many trees were studied because of the wide variations in several variables that appeared to affect felling time, and the apparent need to stratify these variables in the analysis. Tree size, growth habit, and other characteristics were recorded on 182 trees of 15 inches diameter at breast height (d.b.h.) or larger. Felling times were obtained on 133 of these trees. Time breakdowns of sawyer practices were also obtained as opportunities permitted.

[3]*Barger, Roland L., and Ffolliott, Peter F. The physical characteristics and utilization of major woodland tree species in the Southwest. 1970. (In preparation for publication, Rocky Mt. Forest and Range Exp. Sta., U.S. Dep. Agr., Forest Serv., Fort Collins, Colo.)*

Tree Characteristics

Data collected on tree characteristics included stem diameters at d.b.h. and at the cut, number of stems per plant, presence of dead material in stem and crown, crown diameter, tree height, and presence of lean or imbalance. Felling observations included number of undercuts made, vertical cuts to fell separate parts of a split stem, number and size of limbs cut prior to felling, and second cuts to reduce stump height.

Stem and crown conditions complicated measuring. Particular problems were the large variability in crown diameters and heights within stem diameter groups, and the frequency of multistemmed plants (fig. 1). These conditions would also limit photo interpretation. The 182 trees tallied grew as 159 plants, which also had an additional 16 stems less than 15 inches d.b.h. (stems of plants that forked below stump height were considered as individual trees). Crowns of these plants covered 5 percent of the total area.

Tree vigor, as evidenced by partly dead stems and crowns, varied widely. Compare the relatively vigorous crowns and sound stems (fig. 1) with partly dead trees (fig. 4). Vigor did not seem closely associated with size.

About 60 percent of the trees had partly dead crowns, and about the same proportion had dead material in the stem. Crowns classified as partly dead included one or more of these conditions: large dead limbs, many small dead limbs, or dead extremities in most limbs. Partly dead stems either had a "catface" or scar on the exterior of the stem, or more than a third of the cross section at the cut consisted of dry deadwood. Lightning or fire apparently caused most of the stem scars.

Deadwood in the stem is likely to increase felling time. No analysis was made to relate this condition to felling time, however, because of difficulty and doubtful accuracy of determining the amount of dead material in the cross section.

Tree and stand conditions are considered to be typical of many alligator juniper areas.

Figure 1.--Multi-stemmed and low-branching forms limit the use of d.b.h. as a measure of size.

Felling Time in Relation to Tree Characteristics

The need to examine factors that affect felling is pointed up by the extreme variations in felling time, and by the high costs experienced on many trees. Times varied from 1 minute to 2.25 hours per tree. The 133 trees studied required 30.1 man-hours to fell, exclusive of pre-limbing time (cutting limbs preparatory to felling) and time involved in moving between trees. Fifteen trees required 30 minutes or more each to fell.

Felling times or other costs of removal can be related to tree characteristics such as height or stem diameter.[4] Since diameter at the cut is more meaningful in sawing operations and is better than d.b.h. for measuring stem size of alligator juniper trees (fig. 1), it is used in this analysis.

A plot of felling times over diameter shows the relation of certain tree conditions to felling time (fig. 2). Tree conditions that increased felling time are: (1) no appreciable lean or imbalance (fig. 3); (2) low-forked trees on which a second cut was made to reduce a stump height to conform with the treatment requirement of low stumps; and (3) trees on which vertical sawing was required to separate and fell the tree in more than one stem portion (fig. 4).

Above 28 inches in diameter, these special felling problems caused much variability in felling times, and generally high cost. On the basis of these results, four out of five such trees will require from 10 to 45 minutes in felling time, with an average of 20 minutes or more. Problem trees above 28 inches in diameter may need to be considered as a separate group in management decisions.

[4] *The most suitable tree and cost variables will depend on the use of this relationship. For example, Cotner and Jameson (1959) related bulldozing and burning time to height of juniper trees, on the assumption that tree height is a good measure for the use of ranch operators. On the other hand, a relationship of felling time to stem diameter is preferable for use where inventory data on diameters are available, or where stem size is important, as in felling large trees with saws. If desired, d.b.h. (d) and diameter at the cut (D) can be interchanged by means of the following relationships computed from the data for trees 15 to 60 inches d.b.h.*

$$d = 1.15\ D - 3.56$$
$$D = 3.09 + 0.87\ d$$

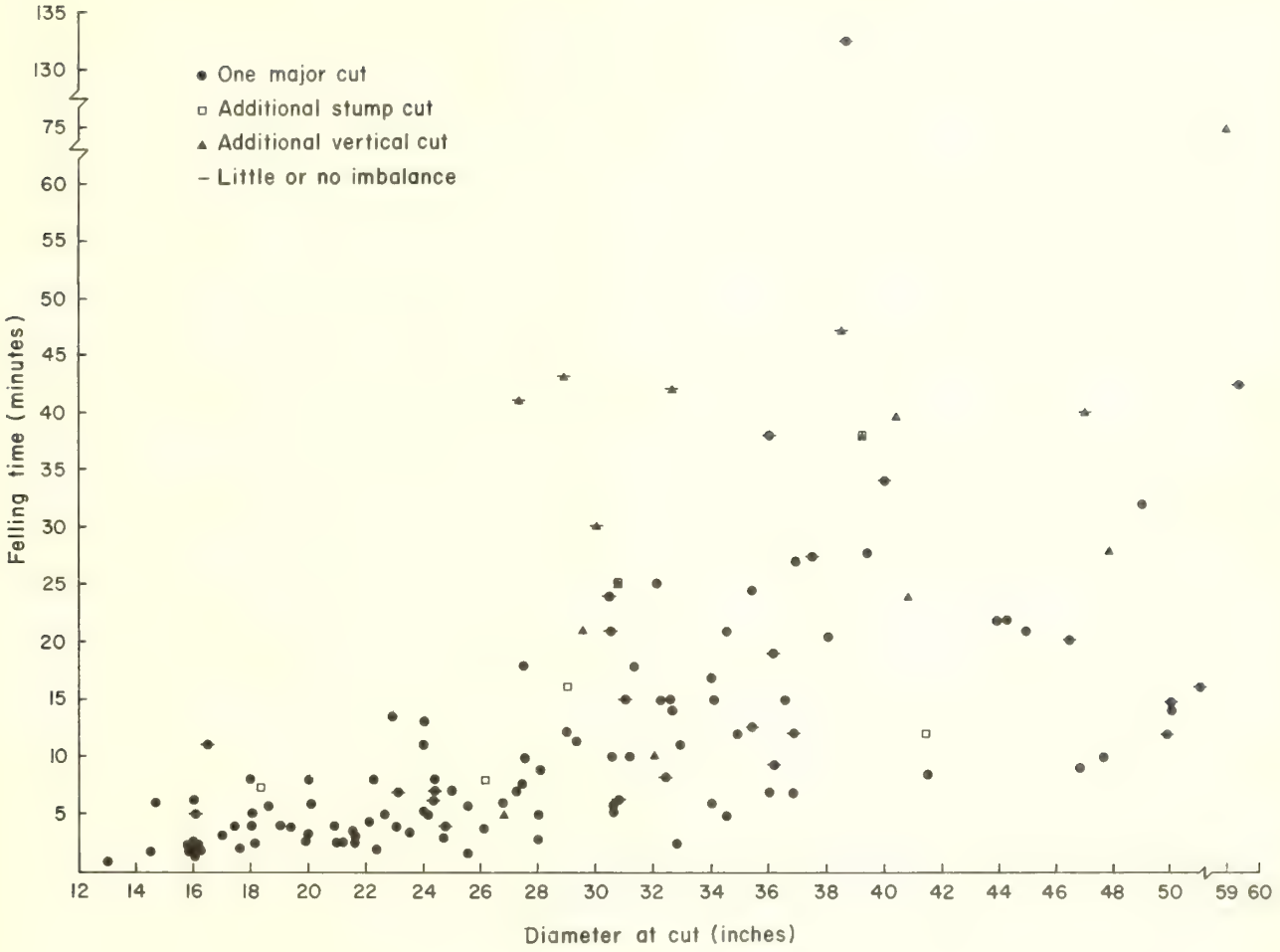

Figure 2.--Felling time of alligator juniper trees in relation to diameter at the cut.

Figure 3.--Trees with little or no imbalance tend to increase felling time. They make judgments on placing cuts and on time of fall difficult, and make felling hazardous. On this tree, an extreme case, the sawyer made five undercuts, cut off three times more than 12 inches in diameter to throw the tree off-balance, and used 2-1/4 hours to fell.

Figure 4.--Frequent partly dead and split stems adversely affect felling time and sawyer safety. They usually require felling in more than one piece with extra safety care, which involves additional undercuts and sometimes vertical cuts to separate pieces.

It should be noted that no trees below 27 inches in diameter had split stems that required felling in more than one piece.

Felling times for trees without special problems are plotted over diameter in figure 5. The regression provides a practical means for estimating felling costs per acre where information on number of trees by diameter class is available. For trees 15 inches in diameter, for example, an average felling time of about 2.5 minutes per tree can be expected. For each additional inch in diameter, felling time can be expected to increase from about 0.3 minute at 15 inches up to about 1 minute at 50 inches.

Sawyer Factors and Working Conditions

Working conditions and sawyer factors also need to be considered for ways to improve efficiency, and in extending results to other situations.

The full crew consisted of five sawyers and a foreman, using chain saws with 28-inch bars. Working conditions were good. No problems were presented by such factors as slope, rockiness, or associated vegetation. Trees tended to be distributed in groups, but spacing was such that safety of nearby workers ordinarily did not affect felling time.

Sawyer skill and experience were found to be especially important. Previous experience of the sawyers consisted mainly of thinning pine stands, where some work practices such as maintaining saw sharpness are likely not as important. Also, larger trees present felling problems that young pine stands do not. In felling the larger trees, especially under the conditions illustrated in figures 3, 4, and 6, sawyer skill must be proportionately much greater, and sawyer factors are more important than with smaller trees.

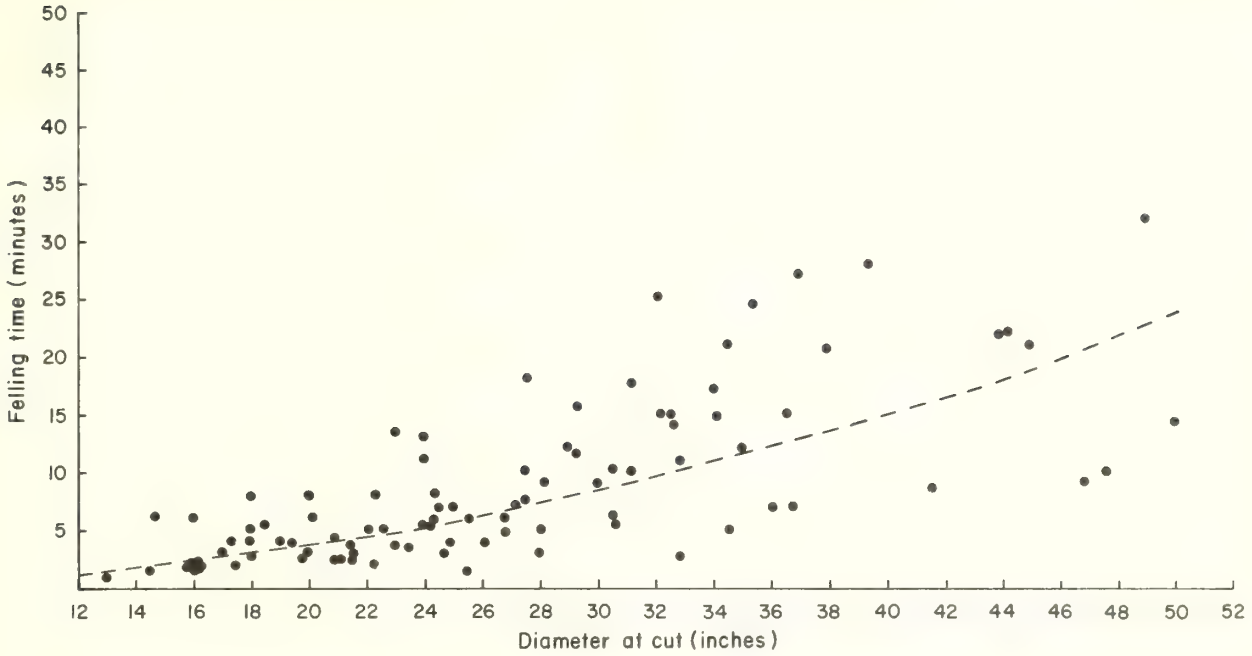

Figure 5.--Estimated regression of felling times of large alligator juniper trees on diameter at the cut.

The wide variations in tree conditions also require much judgment on how to fell, and when a tree is ready to fall. Safety measures tend to increase felling time, especially in the case of larger trees with little lean or imbalance (fig. 3), or split and partly dead stems that require felling in more than one piece (fig. 4). Frequent low-hanging limbs and large limbs on the ground are hazardous in that they obstruct movements (fig. 6). Sawyer safety should be carefully considered, therefore, in prescribing practices for felling large trees.

Times of various sawyer practices were separated for use in determining ways to improve felling efficiency.[5] Actual stem sawing time was recorded on 49 trees, along with notes on the use of time not applied in actual cutting. The proportion of felling time actually spent in cutting ranged from 15 to 100 percent, and averaged 69 percent. This proportion differed among sawyers.

Time not involved in actual cutting of stems was used in pre-limbing, servicing and adjusting saws, moving debris, and making judgments on how to fell. More than half of the trees required limbing; limbing time comprised 8 percent of total felling time for those trees.

Analysis of time breakdowns, and the felling problems discussed above, indicates the possibilities are good for reducing felling time substantially through improved felling methods adapted to the trees, changes in treatment prescription, and sawyer training.

Cost Implications of Some Alternative Practices

Felling costs can be reduced or avoided through alternative practices. For example, all trees with the felling difficulties noted above could be left uncut, or treated by an alternative method. It was previously reported that felling large trees (trees larger than about 9 inches stem diameter at the cut) required about 2.5 man-hours per acre, at a cost of $9.29 per acre.[6] On that basis, if trees

[5] *A more detailed analysis of sawyer practices is being published along with other data, in a separate report by the USDA Agricultural Research Service.*

[6] *Miller, Robert L. Clearing an alligator juniper watershed with saws and chemicals: a cost analysis. 1970. (In preparation for publication, Rocky Mt. Forest and Range Exp. Sta., U. S. Dep. Agr., Forest Serv., Fort Collins, Colo.)*

Figure 6.--

Low branches and severed limbs are hazardous, because they obstruct sawyer movement.

with the particular felling difficulties described were left uncut (less than one tree per acre), the job cost would have been reduced by about 0.47 man-hour per acre, a reduction of 19 percent, or $1.75 per acre.

As another example, 50 percent of the total felling time recorded was used in felling trees of 37.0 inches d.b.h. or larger (a total of 33 trees). Sawyers used 15.5 hours to limb and fell these trees. To leave uncut all trees larger than 37.0 inches would have reduced the total large-tree job cost by about 16 percent, or $1.51 per acre.

A particular treatment feature that increased costs was the requirement for a stump height of not more than 6 inches where practicable, primarily for esthetic reasons. However, practicable height usually turned out to be about 1 foot on the larger trees. In some cases, a second cut was made to reduce stump height. This requirement could easily be relaxed, especially in more remote areas.

Burning of some standing trees could reduce costs substantially. Some trees could be burned easily at little additional cost since some brush was piled, and piles could be placed around trees

to be burned. Although burning has been objected to on esthetic grounds, because of the dead trees left standing, it is possible that some partly dead and deteriorated trees could be almost completely burned.

A treatment could be designed to leave dead trees standing in areas not often observed by recreationists. If groups of live trees are left for esthetic, wildlife, and livestock shade benefits, other standing dead trees may be less conspicuous.

As a further consideration, individual old trees with sparse, partly dead crowns may not have an important effect on either water yields or on forage production, and easily could be left standing.

Some Applications to Juniper Harvesting

Large junipers are not marketable on the stump in any appreciable volume at present. Yet, commercial firewood operators removed all felled juniper stems of 6 inches or larger from the study area. This use of the felled trees indicates the importance of felling costs in restricting development of uses and markets for juniper.

In considering juniper harvesting operations, results from this study can be used in determining costs and in identifying trees that are too costly to fell and use. Many high-cost trees—those with partly dead and deteriorated stems and low forking—would not likely be usable for products other than firewood.

Where fiber volume is the main consideration, it is probable that trees with high felling costs can be eliminated from harvest without much sacrifice in total product volume per acre. For example, inventory estimates for alligator juniper on Beaver Creek indicate that trees larger than 37.0 inches d.b.h. make up only 11.3 cubic feet per acre, or 8 percent of the total volume.[7]

Available juniper volume tables can be used with the results of this study to estimate felling costs per unit volume for juniper trees of different diameters. Estimates for the Beaver Creek area, based on figure 5 and a local volume table,[7] are presented in figure 7. Felling cost per unit volume decreases at first, then increases as diameters become larger (fig. 7). Thus there may be two marginal stem sizes in a given operation. Marginal trees for given operations and markets can be identified by using these data along with information on pay rates, harvesting costs, and product values.

Summary and Conclusions

Costs, in terms of felling time, were affected by extreme variability in tree characteristics. Particular characteristics found to increase felling time were: (1) no appreciable lean or imbalance; (2) low-forked trees on which a second cut was made

[7] *See footnote 3, page 1.*

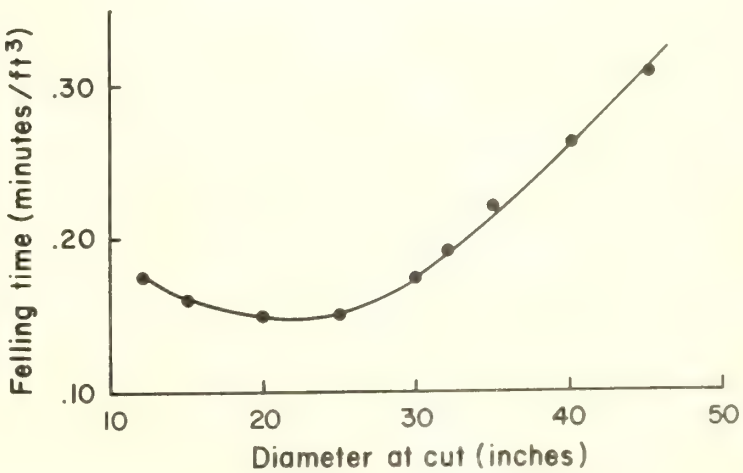

Figure 7.--Felling time per cubic foot as a function of stem diameter at cut (1-foot height).

to reduce stump height to meet a treatment requirement; and (3) deteriorated and split stems which required vertical cuts to fell in more than one piece.

A regression was developed that related felling time to stem diameter for trees without the above problem conditions. Times estimated by the regression range from about 2.5 minutes for trees 15 inches in diameter to 23 minutes at 50 inches.

Sawyer skill and safety are important in felling very large trees and trees with problem characteristics. No problems were experienced in other working and ground conditions. Overall treatment costs can be reduced without much adverse effect by burning, bulldozing, or leaving the high-cost trees untreated.

Results provide a basis for estimating juniper harvesting costs. A functional relationship between stem diameter and felling time per unit volume was established. With other available information, this relationship can be used to identify marginal trees for a given stand, and to estimate minimum market values needed for a profitable operation.

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Miller, Robert L., and Johnsen, Thomas N., Jr.
1970. Effects of tree and sawyer factors on costs of felling large alligator junipers. USDA Forest Serv. Res. Pap. RM-56, 8 p., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

Costs of felling large alligator juniper trees are affected by tree conditions and stem diameter. Conditions that increased felling time were: (1) no appreciable lean or imbalance; (2) low-forked trees on which a second cut was necessary to reduce stump height to meet a treatment requirement; and (3) deteriorated and split stems which required vertical cuts to fell in more than one piece. Sawyer skill and safety were important factors in felling these trees. Possible alternative practices are suggested for trees with these conditions, and for very large trees.

Functions relating felling time and felling time per unit volume to stem diameter are provided. Results can be applied in treatment design and in estimating practice and harvesting costs.

Key words: Alligator juniper, Juniperus deppeana, forestry business economics, tree felling costs.

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- Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.
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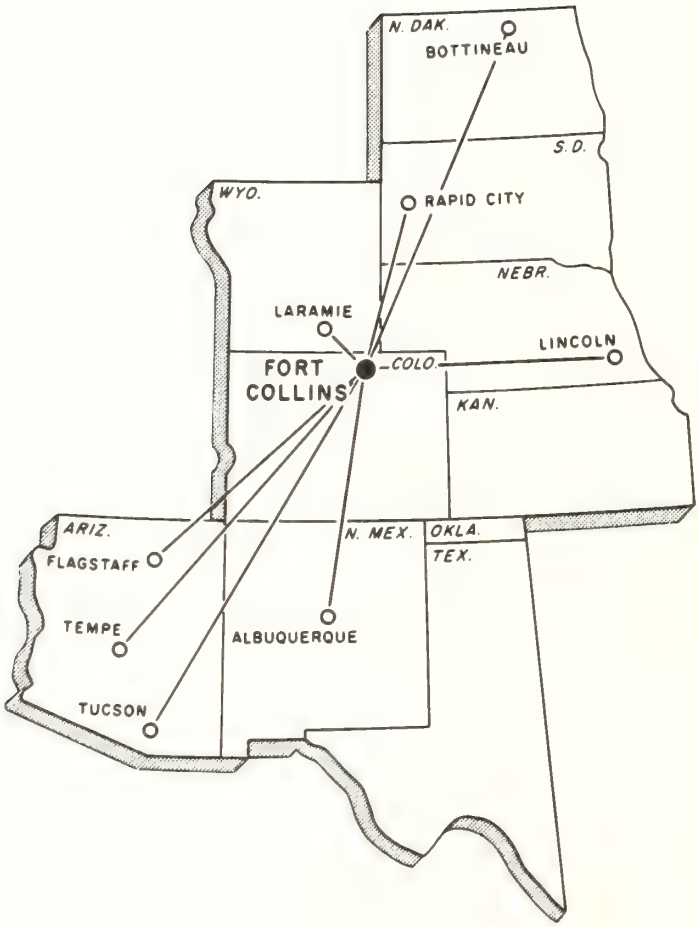
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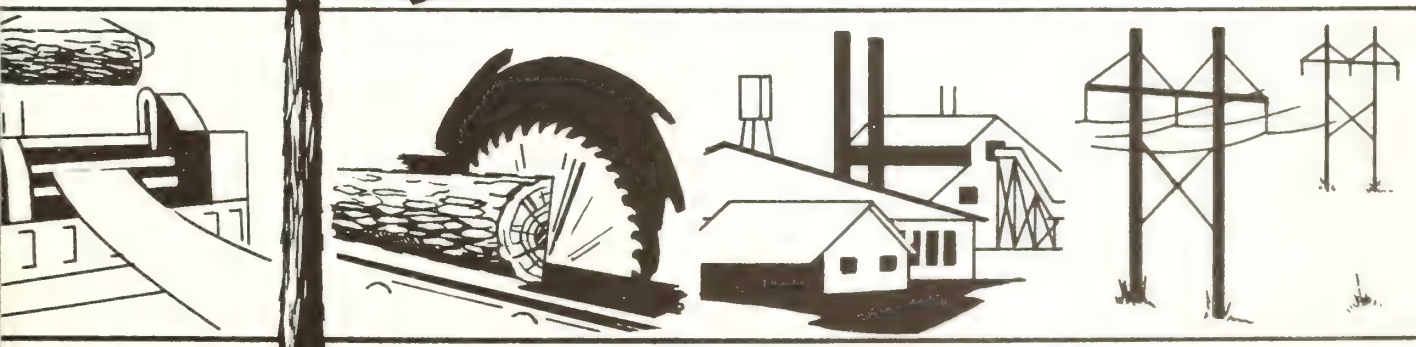
EVALUATING PRODUCT POTENTIAL IN STANDING TIMBER

NOV. 30 1970

Roland L. Barger
and
Peter F. Ffolliott



1970
USDA Forest Service
Research Paper RM-57

Rocky Mountain Forest and Range Experiment Station
Forest Service, U. S. Department of Agriculture
Fort Collins, Colorado 80521

FOREWORD

This paper describes and illustrates a method for evaluating product potential in standing timber. The method will

. . . minimize observer bias in stand quality inventory;

. . . provide a record of the occurrence of stem features that affect product quality and yield;

. . . describe suitability of the standing timber for a broad range of primary products;

. . . provide primary product quality and yield estimates for management and utilization decisions;

. . . provide a continuing basis for such decisions.

ABSTRACT

The timber quality inventory described recognizes and measures the basic stem characteristics and defect features that influence quantity and quality for most primary products. Stem features measured on sample trees include form defects, scar defects, and knot or limb characteristics. Timber inventory data obtained are used in conjunction with standard methods of estimating volume, scaling, and grading to estimate:

(1) Gross volume suitable for a primary product;

(2) Probable volume reduction due to visual scaling defects, and remaining net volume suited to the product;

(3) Quality of the timber in terms of existing grading or quality classification systems.

USDA Forest Service
Research Paper RM-57

1970

Evaluating Product Potential in Standing Timber[1]

by

Roland L. Barger, Principal Wood Technologist

and

Peter F. Ffolliott, Associate Silviculturist

Rocky Mountain Forest and Range Experiment Station[2]

[1]This paper supersedes U. S. Forest Service Research Paper RM-15, "A method of evaluating multiproduct potential in standing timber," issued in October 1965.

[2]Forest Service, U. S. Department of Agriculture, with central headquarters maintained at Fort Collins, in cooperation with Colorado State University; research reported here was conducted at Flagstaff, in cooperation with Northern Arizona University. Ffolliott is currently Research Associate, University of Arizona, Tucson.

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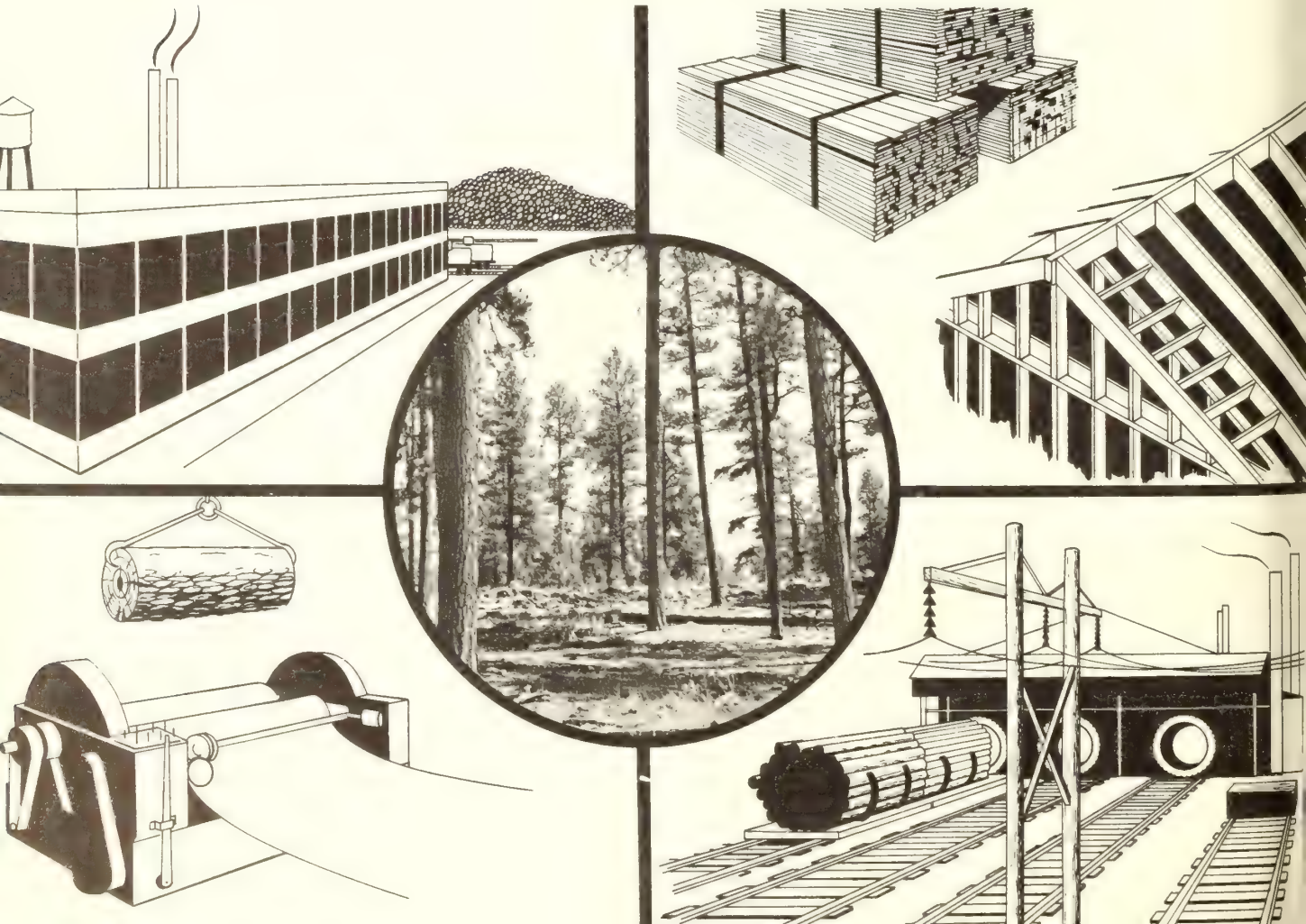


Evaluating Product Potential in Standing Timber

Roland L. Barger and Peter F. Ffolliott

Accent on Quality

Patterns of forest utilization are changing, with added emphasis on new products, new conversion methods, and broader product diversification. Industry trends are toward utilization complexes capable of producing a range of products. These changes call for improved methods of evaluating timber quality.[3] Estimating product potential in standing timber is particularly complicated by the array of products that may warrant consideration. Inventory methods are needed that permit evaluating suitability for all primary products of interest. Ideally, such methods should estimate both quantity and quality of timber suited to each product.

An inventory of timber quality should identify and measure in standing timber the fundamental stem characteristics related to quality and yield. Inventory information may then be interpreted in terms of any existing or proposed grading or quality classification system to estimate suitability of the stand for primary products of interest.

To be most effective, quality inventory methods should avoid applying single-product grading systems directly to standing timber. Stem quality described in terms of a single set of fixed grades is entirely inadequate for multiproduct evaluation. In addition, conventional grading systems are subject to frequent revision, refinement, and regional modification. Basic quality information can be independent of specific grading systems, yet adaptable to any grading system or set of quality criteria in use. Changes in quality requirements or grading specifications for a product then require only a reevaluation of the basic stem quality data originally inventoried.

The detail incorporated in an inventory system must necessarily be a compromise between information desired and time and effort required to get it. A workable inventory system cannot be encumbered with so much detail that it becomes too difficult and time consuming to apply on the ground. Consequently, an inventory of timber quality must record major stem characteristics that affect quality or yield, under relatively broad classifications of severity of defects.

The purpose of this Paper is to describe a method of inventorying quality in standing timber, and using the resulting quality data to estimate potential for a variety of primary products. The system has been developed in southwestern ponderosa pine (Pinus ponderosa Laws.) stands, for the range of primary products for which ponderosa pine is potentially suited (fig. 1). The basic methodology can be applied with little difficulty to other areas and other species.

[3] *Timber quality, as used here, refers to degree of suitability for one or more primary products.*

Figure 1.--Mature stands of ponderosa pine timber are well suited to a wide variety of products. Improved methods of evaluating timber quality are needed to guide choices between alternative products.

Design of the System

Quality for most primary products is largely determined by the same few stem features—stem form defects, scar defects, and presence of knots or limbs. Stem form and scar defects are also the major visual scaling defects in log products. Design of the inventory system requires that such defects be classified or measured by field crews, along with more conventional information such as species and size. Estimates of quality and quantity of timber suitable for any or all primary products of interest are subsequently determined by office or automatic data processing (ADP) procedures.

In developing the methods used, major design considerations were:

(1) To recognize or measure basic stem characteristics and defects that are common grading and/or scaling criteria for most primary products;
(2) To minimize quality evaluations by inventory crews (that is, minimize observer bias) by avoiding field use of conventional tree or log grading systems;
(3) To strike a reasonable compromise between information desired and time and effort required to conduct the inventory.

Quality-related Stem Characteristics

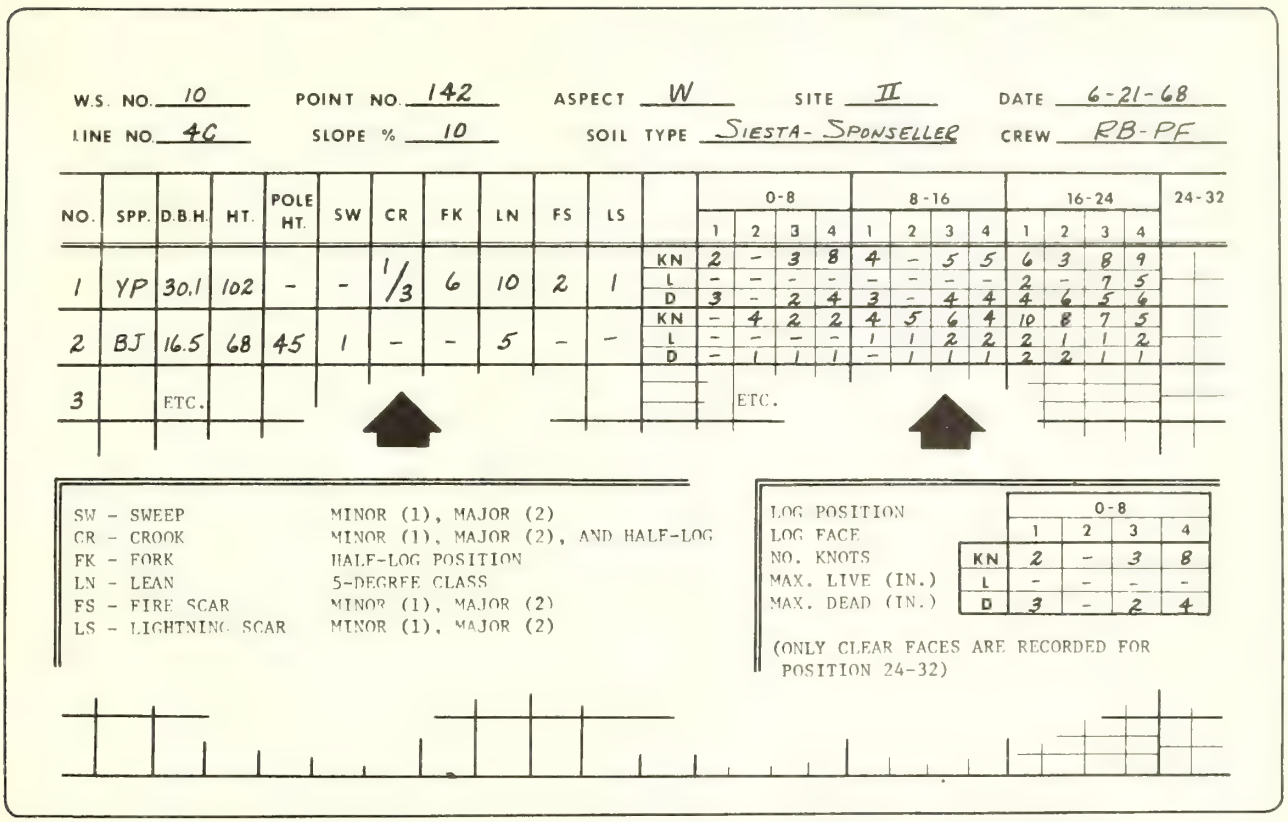
The inventory system relies upon observation or measurement of the following visual stem characteristics, all directly related to timber suitability, grade, or volume for one or more primary products:

Tree stem characteristic	Implications for use, quality, quantity	Inventory data needed
Species	Indicates range of primary products for which stem may be considered.	Species
Age class or form class	Basic indicator of merchantability for some products such as commercial poles. May contribute to volume estimation.	Class such as "blackjack"
Size	Basic indicator of merchantability for all primary products. Determines gross volume for all primary products.	D.b.h., height
Sweep	Limits use for products requiring straight stem. Scaling defect in log products.	Severity
Crook	Limits use for products requiring straight stem. Scaling defect in log products.	Severity and location
Fork	Inadmissible in all primary products. Associated crotch and distorted grain a scaling defect in log products.	Location
Lean	Indicator of possible reaction wood, limiting use for some products.	Severity
Fire or basal scar	Limits use of portion of stem. Scaling and grading defect in log products.	Extent
Lightning scar	Limits use for some products. Scaling and grading defect in log products.	Extent
Knots or limbs	Use for some products limited by knot size. Primary grading criteria for all log products.	Occurrence (number, type, size); distribution

The stem characteristics included are those most indicative of product potential for the range of primary products obtained from ponderosa pine and associated softwood species. Observed stem quality characteristics may be revised for application to other species with significantly different product possibilities.

Sampling Design

The inventory system is concerned primarily with how to observe, record, and interpret the characteristics and defects of individual sample trees. Sampling techniques are not of direct concern. Any valid sampling system that meets timber inventory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SW - SWEEP MINOR (1), MAJOR (2)
CR - CROOK MINOR (1), MAJOR (2), AND HALF-LOG
FK - FORK HALF-LOG POSITION
LN - LEAN 5-DEGREE CLASS
FS - FIRE SCAR MINOR (1), MAJOR (2)
LS - LIGHTNING SCAR MINOR (1), MAJOR (2)
LOG POSITION
LOG FACE
NO. KNOTS
MAX. LIVE (IN.)
MAX. DEAD (IN.)
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L - - - -
D 3 - 2 4
(ONLY CLEAR FACES ARE RECORDED FOR POSITION 24-32)

Figure 2.--Inventory information on stem quality can be recorded for sample trees on a tree data sheet or card with the format illustrated. The entries shown illustrate the manner in which major stem features of two sample trees might be recorded.

sampling objectives can be used as the "vehicle" for the quality inventory system. Reliability of estimates drawn from inventory data will depend, however, upon sampling procedure and intensity.

Recording Inventory Data

Stem quality information is obtained from each sample tree designated by the sampling scheme used. Quality inventory has generally been limited to trees large enough to produce pole or log products. Quality information for smaller trees may be useful, however, in indicating probable suitability of the future timber crop for specific primary products.

Inventory information may be recorded on field data cards or sheets (fig. 2), or may be punched on coded Port-a-punch[4] data cards. Both methods have been used without difficulty.

[4]*Trade names and company names are used for the benefit of the reader, and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.*

The specific measurements or classifications used in recording field information include:

Stem characteristics	How determined	Classification
Species	Observation	Species
Age class or form class	Observation	Class: (for ponderosa pine, coded under species as YP--yellow pine, BJ--blackjack).
Size	Measurement	D.b.h. in inches.
		Total height in feet or in logs (sample as required for volume determination).
		Pole height (where applicable) as maximum 5-foot height class.

Figure 3.--Sweep, defined as a gradual bend in the merchantable stem, affects suitability and yield for many end uses.

Stem characteristics:
Sweep (fig. 3)

How determined:
Estimation

Classification:
Class 1 (Minor)--Deviation of merchantable stem, in inches, less than tree d.b.h.

Class 2 (Major)--Deviation of merchantable stem, in inches, equal to or greater than tree d.b.h.

Note: Sweep judged to be less than 1/3 tree d.b.h. is not considered a defect, and is ignored.

Stem characteristics:
Crook (fig. 4)

How determined:
Estimation and measurement of location

Classification:
Class 1 (Minor)--Deviation of stem in inches, less than 1/2 diameter of stem at crook.

Class 2 (Major)--Deviation of stem, in inches, equal to or greater than 1/2 diameter of stem at crook.

Location: Half-log (8-foot section) height in tree.

Figure 4.--Crook, an abrupt bend in the merchantable stem, is a common grading and scaling defect.

Stem characteristics:
Fork (fig. 5)

How determined:
Measurement of location

Classification:
Location: Half-log (8-foot section) height in tree.

Figure 5.--A fork, or division of the merchantable stem, affects both yield and grade.

Stem characteristics:
Lean (fig. 6)

How determined:
Measurement, using plumb-bob device (fig. 7)

Classification:
Class: 5-degree classes.

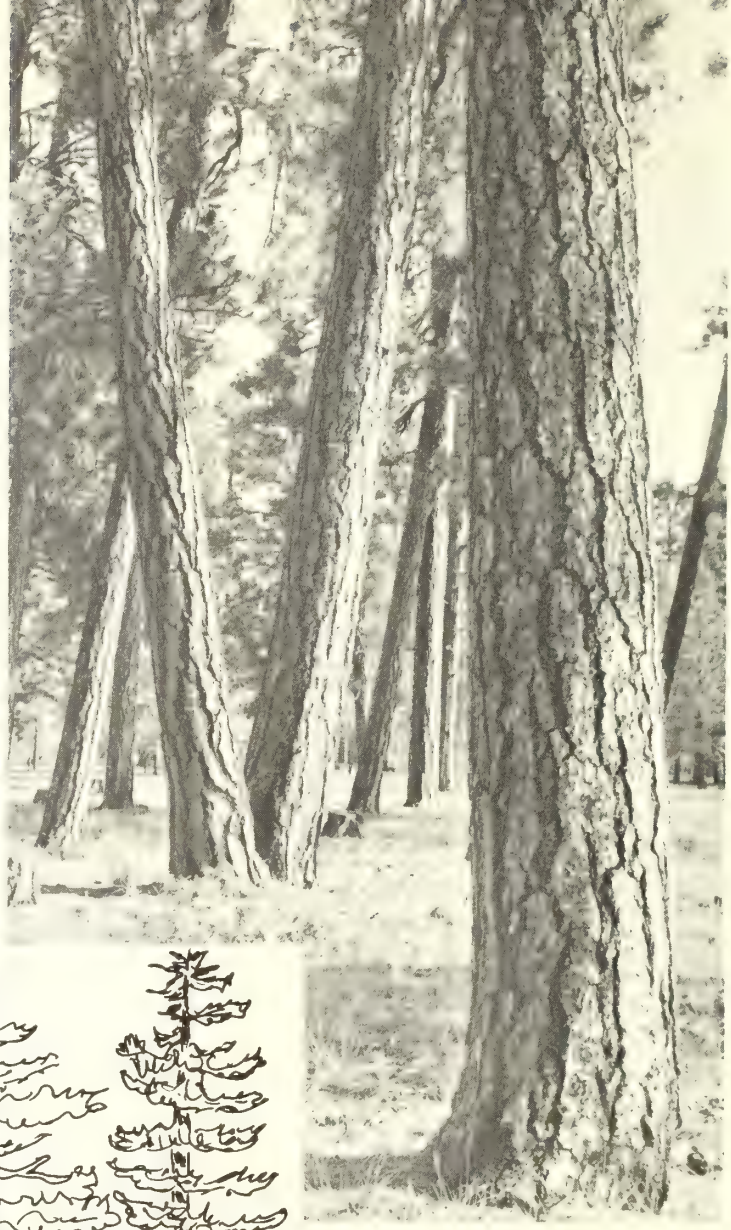


Figure 6.--Leaning stems frequently develop compression wood, a limiting defect for many end uses.

Figure 7.--A plumb-bob device can be used to determine degree of stem lean.

Stem characteristics:
Fire or basal scar (fig. 8)

How determined:
Estimation

Classification:
Class 1 (Minor)--Contained in one stem face (1/4 circumference).

Class 2 (Major)--Extends to two or more stem faces.

Figure 8.--Fire scars may affect one or more faces of the merchantable stem, but seldom extend far up the stem.

Figure 9.--Many lightning strikes cause only superficial physical damage to the merchantable stem. Depending upon the objectives of the inventory, this type of scar may be ignored, or may be recorded separately.

Stem characteristics:
Lightning scar (figs. 9, 10)

How determined:
Estimation

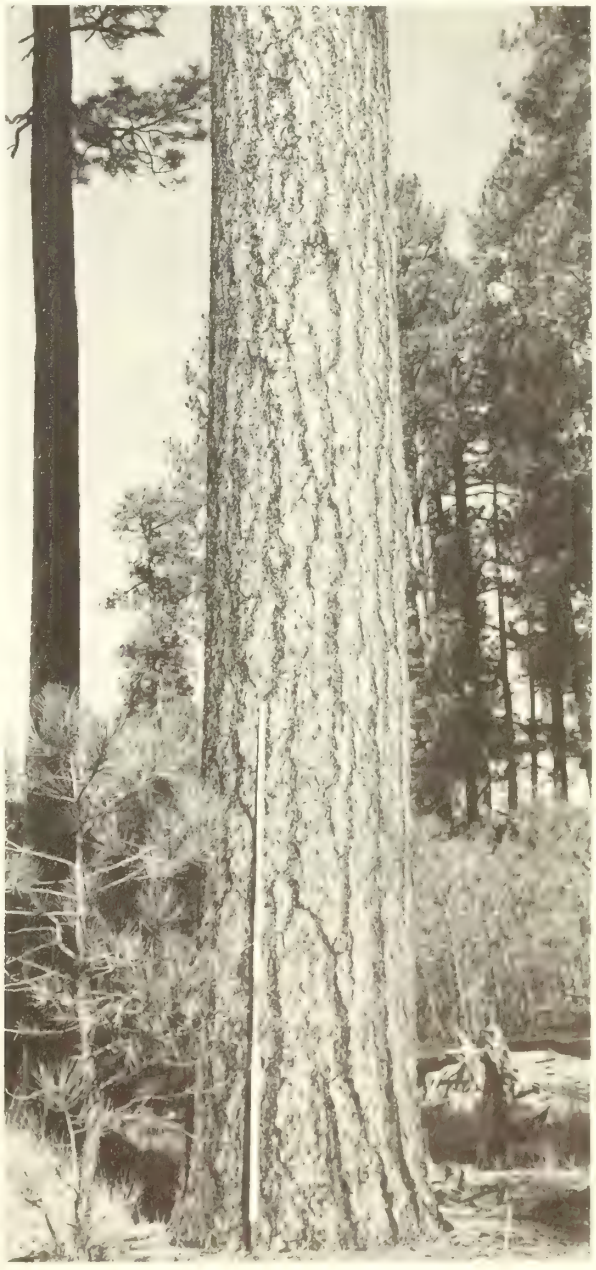
Classification:
Class 1 (Minor)--Essentially straight; contained in one stem face.

Class 2 (Major)--Spiral; extends to two or more stem faces.

Figure 10.--Severe lightning scars and associated fire damage may warrant extensive grade and yield reductions.

Figure 11.--Poor stem characteristics in open-grown stands can severely limit product potential. Knots or limbs are the most important single quality indicator for most primary products.

Figure 12.--Clear log faces indicate maximum and high quality for most primary products.



Stem characteristics:
Knots (figs. 11, 12)

How determined:
Count observation, and estimation

Classification:
For each face of first three merchantable half-logs (8-foot stem sections between stump and 24 feet):
Number of knots in face,
Size of largest live knot or limb to nearest inch,
Size of largest dead knot or limb to nearest inch.

For fourth merchantable half-log (24 to 32 feet):
Occurrence of clear half-log (8-foot) faces.

Knot features are the most difficult to observe and record in some meaningful manner, and at the same time are the most important quality indicator for many primary products. The system of knot count and size estimation by 8-foot stem section and log face was developed through trial and error. More detailed information for lower logs would require excessive inventory time, and knot information of any kind above 32 feet is not generally warranted by the grade potential of upper logs. Field crew training exercises have indicated that knot information observed and recorded as outlined is relatively consistent or reproducible among crews.

Field crews can use telescoping or jointed fishing rods, marked at stump height and at 8- and 16-foot levels above the stump, for locating 8-foot stem sections. The rod also serves as a reference point from which to estimate the four faces or panels of each 8-foot stem section.

The stem quality features observed are those believed most indicative of suitability and yield for a wide range of products. When other features are considered important in determining quality for particular uses, they may be added to the inventory. For example, density or specific gravity is a desirable index to suitability for some uses. Where it is of prime interest, increment cores can be taken from selected sample trees (fig. 13) and specific gravity determinations made. Increment cores or other visual indicators may be used to estimate occurrence of internal rot.

Figure 13.--Where wood quality or internal defect is of particular interest, increment cores can be taken from selected sample trees for further analysis.

Interpreting Inventory Data

The timber inventory data obtained provide a means of readily estimating stand potential for a wide variety of primary products. The data are used in conjunction with standard methods of volume estimation, scaling, and grading to estimate:

(1) Gross volume suitable for a primary product;
(2) Probable volume reduction due to visual scaling defects, and remaining net volume suited to the product;
(3) Quality of the timber in terms of existing grading or quality classification systems.

Figure 14 illustrates the manner in which inventory data are combined with existing methods of estimating volume and grade.

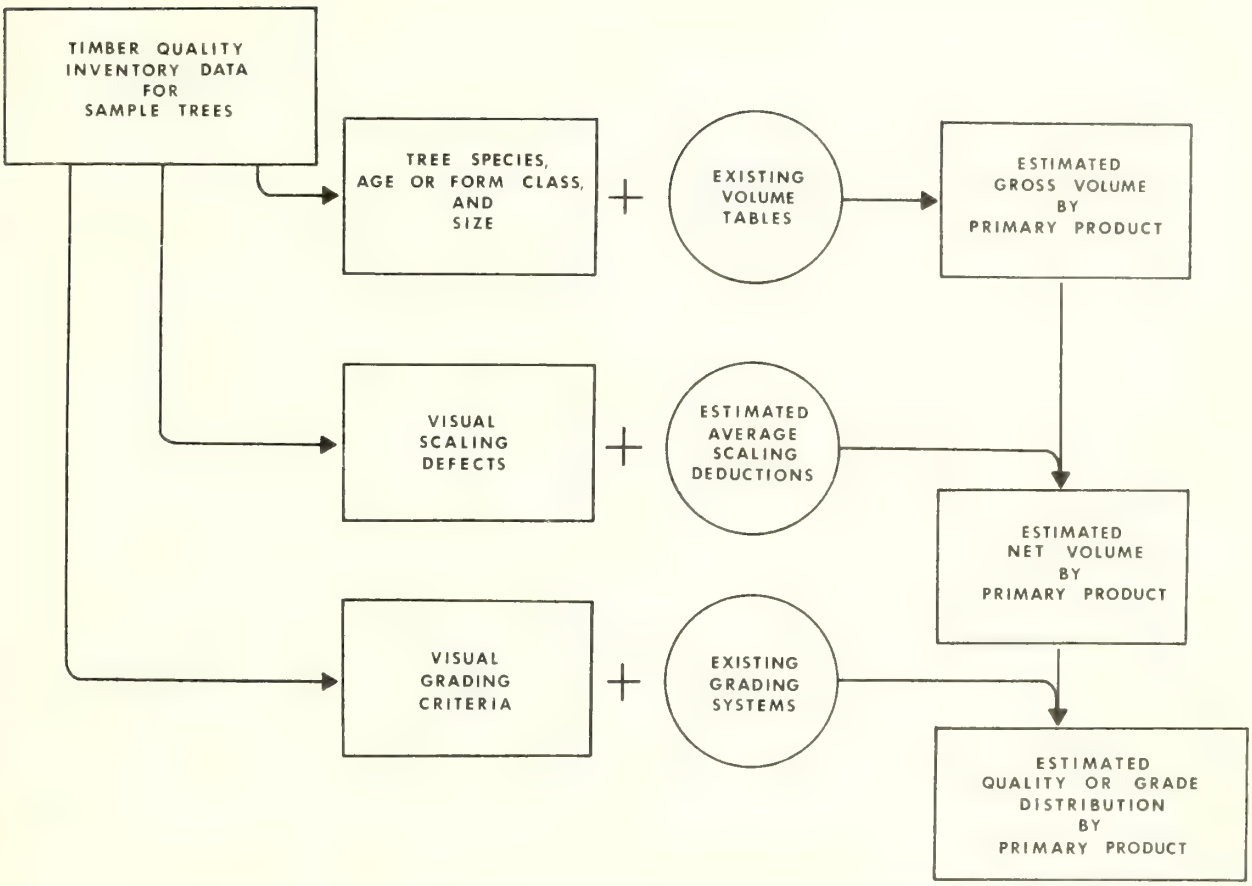

TIMBER QUALITY INVENTORY DATA FOR SAMPLE TREES
TREE SPECIES, AGE OR FORM CLASS, AND SIZE
EXISTING VOLUME TABLES
ESTIMATED GROSS VOLUME BY PRIMARY PRODUCT
VISUAL SCALING DEFECTS
ESTIMATED AVERAGE SCALING DEDUCTIONS
ESTIMATED NET VOLUME BY PRIMARY PRODUCT
VISUAL GRADING CRITERIA
EXISTING GRADING SYSTEMS
ESTIMATED QUALITY OR GRADE DISTRIBUTION BY PRIMARY PRODUCT

Figure 14.--Inventory data for sample trees are used in combination with standard procedures for estimating volume, scaling, and grading to evaluate primary product potential.

Inventory data can be analyzed by hand or by computer procedures. Since the quality of the sample trees must be evaluated individually, machine data processing methods offer considerable advantage. Initial data preparation depends upon which method is to be used. For computer analysis, all inventory data for each tree are punched on data cards. All inventory information described can be placed on one card per tree (fig. 15). Subsequent analysis for each product can be programed.[5] If hand analysis is used, the procedure can be facilitated by first aggregating inventory data into a series of stand tables showing number of trees per acre and frequency of occurrence of each type of stem defect, by tree diameter classes.

[5] *A computer program developed to analyze product potential, using the described timber inventory data, has been prepared by Jack D. Heidt and Donald A. Jameson in "Determining timber conversion alternatives through computer programing," unpublished manuscript, Rocky Mt. Forest and Range Exp. Sta., Flagstaff, Ariz.*

Estimating Gross Volume

Gross volume for most primary products is the total volume contained in trees of acceptable size and form. Gross volume for each product of interest is obtained by applying standard or localized volume tables to the tree stand table developed from inventory data. Size limitations for a product will initially determine the timber to be included in gross volume. Stem size limitations used in estimating gross product volumes in ponderosa pine timber are indicated in table 1. Other stem characteristics may also occasionally be used to define gross product potential; commercial pole potential, for instance, may include only stems of a particular form or age class in addition to size limits.

Estimating Net Volume

Net volume for each product is obtained by estimating reductions in usable material due to visual

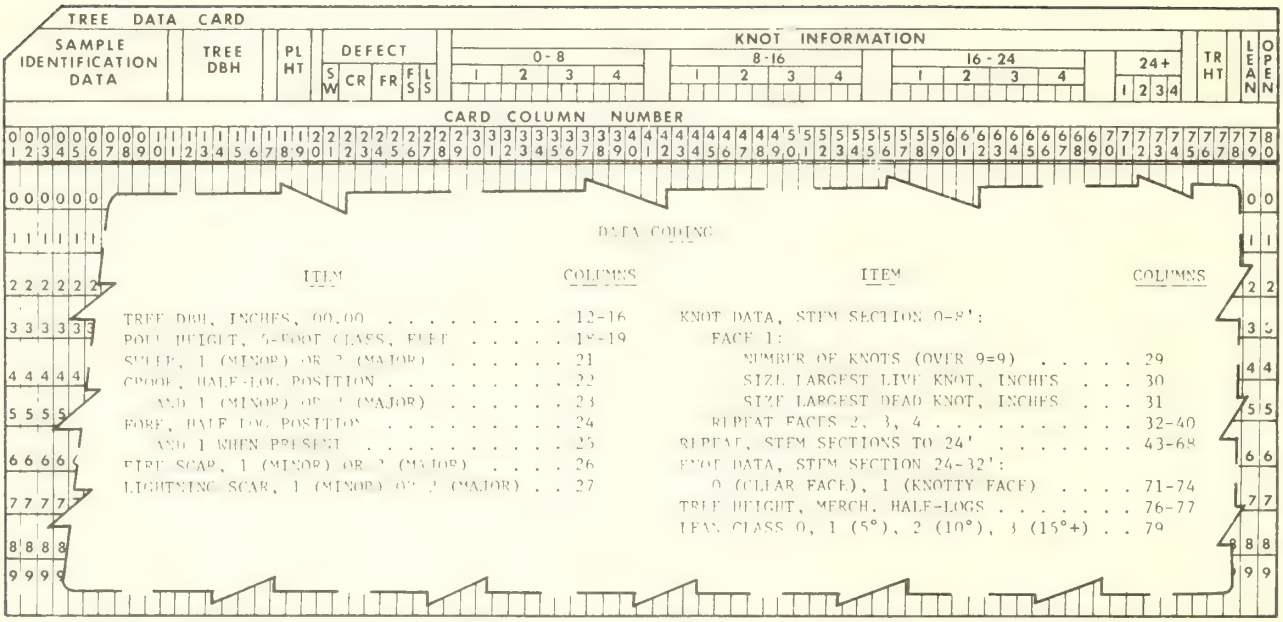

TREE DATA CARD
SAMPLE IDENTIFICATION DATA
TREE DBH
PL HT
DEFECT
SW CR FR FS LS
KNOT INFORMATION
0 - 8
8 - 16
16 - 24
24+
1 2 3 4
TR HT
LEAN
OPEN
CARD COLUMN NUMBER
DATA CODING
ITEM
COLUMNS
TREE DBH, INCHES, 00.00 12-16
POLE HEIGHT, 5-FOOT CLASS, FEET 18-19
SWEEP, 1 (MINOR) OR 2 (MAJOR) 21
CROOK, HALF-LOG POSITION 22
AND 1 (MINOR) OR 2 (MAJOR) 23
FORK, HALF LOG POSITION 24
AND 1 WHEN PRESENT 25
FIRE SCAR, 1 (MINOR) OR 2 (MAJOR) 26
LIGHTNING SCAR, 1 (MINOR) OR 2 (MAJOR) . . 27
ITEM
COLUMNS
KNOT DATA, STEM SECTION 0-8':
FACE 1:
NUMBER OF KNOTS (OVER 9=9) 29
SIZE LARGEST LIVE KNOT, INCHES . . . 30
SIZE LARGEST DEAD KNOT, INCHES . . . 31
REPEAT FACES 2, 3, 4 32-40
REPEAT, STEM SECTIONS TO 24' 43-68
ENDF DATA, STEM SECTION 24-32':
0 (CLEAR FACE), 1 (KNOTTY FACE) 71-74
TREE HEIGHT, MERCH. HALF-LOGS 76-77
LEAN CLASS 0, 1 (5°), 2 (10°), 3 (15°+) . . 79

Figure 15.--To facilitate computer analysis of inventory data, all information for one sample tree can be punched on a single data card with the format illustrated.

Table 1.--Stem characteristics used in estimating suitability, volume, and grade for primary products in ponderosa pine

Primary product	Stem size limitations	Visual defects limiting use or reducing usable volume (scale)[1]	Visual grading criteria	Nominal product unit
Saw logs	Tree d.b.h., 11.0 inches and over	Sweep, crook, fork, fire and basal scar, lightning scar	(First 32 feet) Knot number and distribution; scar defects	Board feet, 16-foot logs
Veneer logs	Log scaling diameter, 11.0 inches and over	Crook, fork, fire and basal scar, lightning scar	(First 24 feet) Dead knot size; live knot size	Board feet, 8-foot logs
Stud logs	Log scaling diameter, 6.0 to 16.9 inches[3]	Crook, fork, fire and basal scar, lightning scar	(First 24 feet) Knot number; dead knot size; live knot size	Board feet, 8-foot logs
Commercial poles	Tree d.b.h., 9.0 to 20.9 inches	Sweep, crook, fork, lean, fire and basal scar, lightning scar, oversized knots	Merchantable pole height; tree d.b.h.	Piece count, 5-foot height classes
Pulpwood	No limit in initial evaluation	Crook (in groundwood), fire scar, lightning scar	None	Cubic volume

[1]Includes defects that either prohibit use of the stem or stem section for the product, or reduce merchantable volume for the product.
[2]Limits stem sections evaluated for veneer to first section in trees in 12-inch diameter class; first and second sections in 14-inch class trees; three sections in all trees larger.
[3]Limits stem sections evaluated for studs to three sections in trees in 18-inch and smaller diameter classes; second and third sections in 20-inch class trees; third section in 22-inch class trees; none in larger trees.

stem defects. Defects considered to affect suitability or volume for primary products in ponderosa pine are shown in table 1. Depending upon the primary product being evaluated, recorded stem defects may prohibit use for the product altogether, or may reduce usable volume for the product. For example, major crook will prohibit use of a stem for a pole, but will only reduce usable volume or scale in a saw log.. For those defects judged to prohibit use for the product, gross volume (or count) is reduced by the volume (or count) contained in trees or tree sections with the defect. Examples are

removal of trees with recorded sweep from gross stem count for pole potential, and removal of 8-foot stem sections with major crook from gross volume for veneer logs.

For defects judged to reduce usable volume for a product (scaling defects), average scaling deductions are applied to gross volume. Average scaling deductions for each type of defect may be estimated by referring to standard scaling procedures and methods (Grosenbaugh 1952, U. S. Forest Service 1964). As an example, average deductions used in evaluating product potential in ponderosa pine included:

Visual scaling defect	Scale deduction applied
Sweep	
(1) Minor	None (largely removed in bucking).
(2) Major	Deduct 20 percent of merchantable volume in entire stem.
Crook	
(Minor and major)	Deduct volume equivalent to 4 feet of length of log in which it occurs (25 percent of 16-foot log).
Fork	Deduct volume equivalent to 4 feet of length of log in which it occurs (25 percent of 16-foot log).
Fire or basal scar	
(1) Minor	None (contained outside right scaling cylinder).
(2) Major	Deduct volume equivalent to 2 feet of length of butt log (12-1/2 percent of 16-foot log).
Lightning scar	
(1) Minor	Deduct 25 percent of volume in entire stem.
(2) Major	Deduct 50 percent of volume in entire stem.

Computer techniques will include the capability to scan defect data by individual tree and stem section, and make specified corrections to gross volume for each product. If calculations are being performed by hand, however, it is most convenient to start with stand tables showing gross product volume by log position and tree diameter class. Scaling deductions can then be applied by log position (where applicable) and tree diameter class. For a particular scalable defect and tree diameter class or log position, corrections to gross volume may be calculated as:

Percent occurrence of defect	X	Percent scaling deduction	=	Percent correction to gross volume

Diameter class information can then be combined to show total deductions by defect type, and total net volume for the primary product being considered.

Estimating Grade or Quality Class

Quality or grade of the net volume of material acceptable for each primary product is also important. Choices between alternative products will frequently be based upon the apparent grade of the timber for each potential product. For some primary products such as poles, quality may be adequately expressed by height and diameter class. For others such as saw logs and veneer logs, an estimate of log grade distribution is needed. Grade or quality class is estimated by interpreting recorded stem quality information in terms of existing grading systems. The precision with which grades or quality classes can be estimated depends largely upon the nature of the grading system being used. More complicated grading systems will obviously require more extensive interpretations of the data.

Quality evaluation can be accomplished either by programed computer procedures or by hand. In either case, each sample tree must be evaluated individually. Hand evaluations can be made directly from field data cards similar to that in figure 2.

Grading systems for conversion products such as saw logs and veneer logs necessarily include only visible stem characteristics as grading criteria. Most are based primarily on size, number, and distribution of log knots. Consequently, the grade of a log can be estimated by comparing recorded stem defect data with grade specifications. Depending upon the grading system used, this may involve scanning knot data only, or may require additional consideration of scars and stem form defects.

Using Inventory Data — An Example

Methods and procedures for interpreting inventory data have thus far been discussed in general

terms. They can best be clarified and illustrated in an example. The following analysis is an actual application of the inventory system in estimating the product potential of a timber stand.

The Area and Timber

The example area is a 430-acre watershed in cutover ponderosa pine. Timber was last logged from the area 20 years ago, leaving approximately half of the merchantable volume in the residual stand. The current stand includes approximately 85 percent ponderosa pine and 15 percent associated woodland species. Pine timber was inventoried on the area, by means of the quality inventory methods described, with a sample design of 200 point samples systematically located along multiple random starts.

Basic inventory data for the stand were aggregated into stand tables in preparation for hand analysis. Stand data and stem defect occurrence data are summarized in table 2. Knot data were "read" directly from inventory cards when needed to complete the analysis.

Primary Product Potential

For the locality and timber used in the example, five primary products were considered: saw logs, veneer logs, stud logs, commercial poles, and pulpwood. Although local markets are not currently active for all these products, their development in the near future seems imminent. The manner in which recorded quality data can be applied in estimating product potential is amply demonstrated by this group of products.

Saw log potential.—All timber in diameter classes 12 inches and larger was considered potential sawtimber. Gross volume of this timber was obtained by converting stand measurement data into board feet Scribner scale by means of volume tables (Myers 1963). A high proportion of the merchantable volume was contained in butt 16-foot logs, and only a minor proportion occurred above the second log. The gross volume in each diameter class and proportion of volume by log position is shown in the left-hand columns of table 3.

Net saw log volume was estimated by adjusting gross volume for visual defect. For the timber considered, major sweep, crook, fork, and fire and lightning scars will reduce usable saw log volume. Deductions within each tree diameter class were calculated for each of these defects by applying inventory defect occurrence data and the average scale deduction factors previously described (page 13).

For example, the scale deduction for crook in the 16-inch tree diameter class was calculated as:

Table 2.--Ponderosa pine timber stand, per acre basis, and percent of stems with defect, on example area

Tree d.b.h. class (Inches)	Trees per acre	Volume per acre	Summary of stem defect occurrence													
			Sweep		Crook		Fork				Lean			Fire scar		Lightning scar	
			Minor	Major	First log	Second log	Over	First log	Second log	Over		10°	15°+	Minor	Major	Minor	Major
	Number	Board feet	- Percent -														
8	22.50	--	3.0	3.2	10.0	1.6	0	0	0	0	8.0	1.6	0	.0	1.6	0	0
10	13.00	196	2.0	1.8	9.0	3.6	0	0	0	0	10.8	1.8	0	0	0	0	0
12	7.43	334	0	0	8.6	6.2	0	0	0	0	8.7	[illegible]	2.2	0	0	0	0
14	2.14	161	0	0	10.6	0	0	0	0	0	16.0	5.3	0	0	0	0	0
16	1.82	200	5.0	4.9	9.8	4.9	0	0	4.9	0	14.8	19.8	0	0	0	0	0
18	2.23	357	9.0	10.3	6.8	0	0	3.4	0	0	20.6	6.7	3.4	0	3.4	0	6.7
20	1.40	348	0	0	4.1	4.1	0	0	4.1	8.0	28.3	4.1	8.3	4.1	0	4.1	4.1
22	1.68	596	0	0	2.9	2.9	0	0	0	0	28.6	8.3	2.9	2.9	0	0	5.9
24	1.13	521	0	0	0	7.0	3.0	0	0	0	21.2	10.6	0	0	3.5	3.5	21.2
26	.79	471	4.0	3.6	0	3.6	4.0	0	3.6	8.0	29.3	3.6	3.6	0	0	3.6	8.5
28	.27	196	0	0	0	0	0	0	0	0	51.7	10.3	10.3	0	0	20.7	10.3
30	.13	112	0	0	0	0	0	0	0	0	0	0	0	13.3	0	0	13.3
32	.05	47	0	0	0	0	0	0	0	0	50.0	0	0	0	0	0	0
34	.02	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	.02	24	0	0	0	0	0	0	[illegible]	0	0	0	0	0	50.0	0	50.0
38	.03	49	0	0	0	0	0	0	0	0	0	0	0	40.0	0	0	40.0
Total	54.64	3,636	2.1	2.2	6.3	3.3	.6	.3	.8	1.1	17.4	4.7	2.2	1.1	1.1	1.4	4.7

Note: '--' indicates not applicable.

Table 3.--Analysis of saw log potential, per acre basis, in the example stand

Tree d.b.h. class (Inches)	Gross saw log volume				Deduction for visual defect						Net saw log volume by log and grade							
	Per acre	Distribution by log			Major sweep	Crook	Fork	Major fire scar	Lightning scar	Total	First log		Second log		Upper log		Total	
		First	Second	Upper							Grade 3 & better	Grade 5	Grade 3 & better	Grade 5	Grade 3 & better	Grade 5	Grade 3 & better	Grade 5
	Board feet	- - - - - - - - - -			Percent						Board feet							
12	334	89	11	0	0	2.1	0	0	0	2.1	0	290	0	37	--	--	--	327
14	161	80	20	0	0	2.1	0	0	0	2.1	0	126	0	32	--	--	--	158
16	200	73	27	0	1.0	2.1	.3	0	0	3.4	7	134	0	52	--	--	7	186
18	357	69	31	0	2.1	1.2	.6	.3	3.4	7.6	7	220	0	103	--	--	7	323
20	348	64	32	4	0	1.0	.3	0	3.1	4.4	17	196	0	107	0	13	17	316
22	596	59	31	10	0	.7	0	0	3.0	3.7	31	309	0	178	0	56	31	543
24	521	58	32	10	0	.6	0	.3	11.5	12.4	11	254	0	147	0	44	11	445
26	471	58	33	9	.7	.4	.3	0	5.2	6.6	36	219	0	143	0	42	36	404
28	196	58	33	9	0	0	0	0	10.3	10.3	10	91	0	58	0	17	10	166
30	112	57	34	9	0	0	0	0	6.6	6.6	12	48	0	35	0	10	12	93
32	47	55	34	11	0	0	0	0	0	0	0	26	0	16	0	5	0	47
34	24	53	32	15	0	0	0	0	0	0	12	0	0	7	0	5	12	12
36	24	50	30	20	0	0	0	3.1	25.0	28.1	9	0	0	5	0	3	9	8
38	49	49	29	22	0	0	0	0	20.0	20.0	10	10	0	12	0	7	10	29
Total	3,440	65	29	6							162	1,923	0	932	0	202	162	3,057

[1]Exclusive of volume reduction due to internal defect.
Note: "--" indicates not applicable.

Log position (Number)	Crook occurrence (Percent)		Log scale deduction (Decimal)		Volume in log position fraction)		Defect deduction (Percent)
1	9.8	x	0.25	x	0.73	=	1.79
2	4.9	x	.25	x	.27	=	.33
Over	0	x	.25	x	0	=	0
Total scale deduction (percent)						=	2.12

The scale deduction for sweep in the same size class was calculated more simply, as:

Major sweep occurrence (Percent)		Tree scale deduction (Fraction)		Defect deduction (Percent)
4.9	x	0.20	=	0.98

Since sweep is considered to affect the entire merchantable stem uniformly, defect occurrence and volume distribution by log position do not have to be considered.

Scaling deductions for each type of visual defect, by tree diameter classes, are indicated in table 3. The resulting net volumes, exclusive of internal defect deductions, are also shown.

The improved 5-grade log-grading system (Gaines 1962) is currently recognized for ponderosa pine sawtimber. Quality of the saw log material was estimated by applying grade specifications for this system to recorded stem quality data. In this grading system, log knots are the primary grading defects, while scars and certain stem abnormalities are secondary defects. The grade of a log is determined by the amount of log surface (expressed in 4-foot log face "panels") free of grading defects. To estimate saw log grade for sampled trees, recorded defect information for first and second logs was scanned to determine number of defect-free "panels." Recorded data do not correspond exactly to the grading criteria used in this system, so some interpretive rules of thumb are necessary: one clear 8-foot face = 2 assured clear "panels," an 8-foot face with one knot = 1 assured clear "panel," and so forth. Estimated defect-free "panels" were accumulated for all faces of a log and the appropriate grade assigned the log as follows:

Estimated clear 4-foot panels		
(Full log--16-foot)	(Half log--8-foot)	Grade assigned
- - (Number) - -		(Number)
15 - 16	8	1
12 - 14	6 - 7	2
5 - 11	3 - 5	3
Less than 5	Less than 3	5

Saw log volume above 32 feet in the tree was assigned Grade 5.

An extremely small proportion of the saw log material qualified for Grades 1 and 2, and Grade 4 describes a type of log not commonly found in southwestern ponderosa pine. Consequently, quality

stratification was effectively limited to two classes—"Grade 3 and better" and "Grade 5." The distribution of net saw log volume by log grade and position is shown in the right-hand columns of table 3.

Veneer log potential.—Gross veneer log potential includes all 8-foot stem sections with an estimated scaling diameter of 10 inches or more. Unlike saw logs, however, not all tree volume of acceptable size may meet minimum requirements for the product. Most veneer log grading systems have quality limitations on the lowest acceptable grade. Consequently, the analysis illustrated limits gross veneer log potential to the first 24 feet of merchantable stem, for which detailed quality information is available. Results of the analysis will necessarily be conservative. Gross veneer log volume in each diameter class, and distribution of the volume in the first three 8-foot stem sections, are shown in the left-hand columns of table 4.

Visible stem defects that will reduce usable veneer log volume include crook, fork, and fire and lightning scar. Major crook was considered to remove the entire 8-foot block from consideration for veneer. Minor crook, fork, and scar resulted in scaling deductions equivalent to those made in saw logs. Sweep can usually be eliminated in bucking 8-foot veneer blocks. Defect deductions were calculated in the manner previously illustrated for saw logs. Scaling deductions by type of defect and resulting net **ungraded** log volume—a "first estimate" of net veneer log volume—are shown in table 4. A more refined estimate is obtained when veneer log grades are applied, since some of the ungraded net volume may not meet minimum grade specifications.

The quality of a veneer log depends primarily upon the size of live and dead knots present. To describe the quality of veneer logs in sample stands, an arbitrary grading procedure was adopted. The procedure, based partially on experienced recovery of veneer suited to sheathing grade plywood, uses recorded knot size information to grade each 8-foot veneer block:

Diameters of--		
Dead knots	Live knots	Grade
(Inches)		
None	To 2	1
To 2	To 2	2
To 3	Any size	3
Over 3		Unacceptable

The volume of veneer log material graded "unacceptable" and the acceptable net volume, by grade, is shown in the right-hand columns of table 4. Grades 1 and 2 are combined, since the sampled stand contained only a small volume of Grade 1 material. The quality analysis can readily be adjusted to accommodate different grading criteria or end-product requirements. For example, the effect of allowing 4-inch dead knots in Grade 3 can be evaluated directly from inventory data. In the sampled stand, such a change would substantially reduce the "unacceptable" volume.

Table 4.--Analysis of veneer log potential, per acre basis, in the example stand

Tree d.b.h. class (Inches)	Gross veneer log volume[1]				Deduction for visual defect					Net veneer log volume				
	Per acre	Distribution by 8-foot block			Crook	Fork	Major fire scar	Lightning scar	Total	Ungraded	Graded			
		First	Second	Third							Unacceptable	Grades 1 & 2	Grade 3	Total acceptable[2]
	Board feet	Percent								Board feet				
12	222	100	0	0	4.3	0	0	0	4.3	212	21	85	106	191
14	129	67	33	0	3.5	0	0	0	3.5	124	41	7	76	83
16	182	50	30	20	2.5	.5	0	0	3.0	177	84	46	47	93
18	313	50	29	21	1.3	.9	.4	3.4	6.0	294	134	47	113	160
20	292	43	33	24	1.4	0	0	3.1	4.5	279	165	42	72	114
22	470	43	32	25	.5	0	0	3.0	3.5	454	295	56	103	159
24	403	42	33	25	.4	0	.4	11.5	12.3	353	243	22	88	110
26	362	42	33	25	0	0	0	5.2	5.2	343	274	26	43	69
28	151	41	34	25	0	0	0	10.3	10.3	135	96	6	33	39
30	86	41	33	26	0	0	0	6.6	6.6	80	67	0	13	13
32	35	41	33	26	0	0	0	0	0	35	35	0	0	0
34	17	41	33	26	0	0	0	0	0	17	10	7	0	7
36	17	40	34	26	0	0	5.0	25.0	30.0	12	7	5	0	5
38	33	39	35	26	0	0	0	20.0	20.0	26	26	0	0	0
Total	2,712	49	30	21						2,541	1,498	349	694	1,043

[1]Includes only volume in first 8-foot section of trees in 12-inch diameter class, first and second sections of 14-inch class trees, and first three sections of all trees larger.
[2]Exclusive of volume reduction due to internal defect.

Stud log potential.—Gross stud log volume includes all 8-foot stem sections with scaling diameters of 6.0 to 16.9 inches. Stud logs are typically processed through chipping headrig mills, or mills similarly equipped for the specialty manufacture of studs and dimension stock. As with veneer logs, not all stem sections of the right size may meet minimum quality requirements. The analysis is consequently limited to the first 24 feet of merchantable stem. The maximum scaling diameter limit of 16.9 inches further restricts gross stud log potential to portions of trees in 22-inch and smaller diameter classes. Gross potential volume and distribution by 8-foot stem section are shown in table 5.

The net volume of stud log material was estimated by considering the same scaling defects and deductions applied to veneer logs—crook, fork, and scar. Deductions for visual defect and net ungraded volume are included in table 5.

The quality of a stud log depends upon size and number of knots present. An arbitrary grading procedure, based on log characteristics important in the production of dimension lumber, was used to indicate quality of stud logs in the sample stand. The procedure uses knot size and number information from inventory data to grade each 8-foot log:

Diameters of--		Total knots	
Dead knots	Live knots	allowed	Grade
(Inches)		(Number)	
To 1	To 2	16 or less	1
To 2	To 2	32 or less	2
To 2	To 3	No limit	3
Over 2	Over 3		Unacceptable

The acceptable net volume of stud log material, by grade, and volume unaccepted, are shown in table 5. Grades 1 and 2 are again combined because of the small volume of Grade 1 logs in the sampled stand. The dead knot size limit was primarily responsible for the high proportion of unaccepted material. Again, reevaluation of the inventory data indicates that allowing 3-inch dead knots in Grade 3 would substantially reduce the unaccepted volume.

Pole potential.—Because stems that meet specifications for commercial poles are usually considerably more valuable for that use than for any alternative, pole potential in a stand should receive careful attention. The potential for pole products is not limited entirely to commercial poles, however; poles of shorter lengths are used in quantity as house logs and in pole frame construction. Gross pole potential is expressed in terms of stems per acre, rather that volumetric measurement. All stems in 10-inch through 20-inch diameter classes were initially considered potential poles. Gross pole potential by tree diameter class is shown in table 6.

Standards for commercial poles are defined in specifications of the American Standards Association (1963). Because of critical strength requirements, the standards are detailed and stringent. Defects that render stems unsuitable for poles include sweep, major crook, fork, lightning scar, and excessive lean (indicative of compression wood). Also inadmissible are excessive knots, generally defined for shorter poles as single knots 4 inches or larger in diameter, or knots aggregating over 8 inches in diameter within a 1-foot stem section.

Short commercial poles, and poles too short to meet commercial standards, are used in substantial numbers in pole frame construction and related uses. There are no standard specifications, other than those developed to meet particular design requirements, for short construction poles. The Forest

Table 5.--Analysis of stud log potential, per acre basis, in the example stand

Tree d.b.h. class (inches)	Gross stud log volume				Deduction for visual defect					Net ungraded volume	Net volume by grade		
	Per acre	Distribution by 8-foot log			Crook	Fork	Water fire scar	Lightning scar	Total		1	2	3	Total acceptable
		First	Second	Third										
	Board feet	Percent								Board feet				
10	196	67	33	0	2.4	0			2.4	191	94	5	92	
12	334	67	22	11	3.1	0	0	3.1	324	138	0	186	186
14	150	57	29	14	3.0	0	0	0	3.0	146				52
16	182	50	30	20	2.5	.5	0		3.0	177	87	23		90
18	313	50	29	21	1.3	.9	.4	3.4	6.0	294	149	18	127	145
20	167	0	58	42	2.0	0		3.1	5.1	158	133	0		25
22	118	0	0	100	0		0	3.0	3.0	114				
Total	1,460	47	29	24						1,404				

[1]Includes only volume in first three 8-foot sections of trees in 18-inch and smaller diameter classes, second and third sections in 20-inch class trees, third section in 22-inch class trees, and none in larger trees.
[2]Exclusive of volume reduction due to internal defect.

Products Laboratory has recommended, however, that poles used for framing meet American Standard or equivalent grades (Wood 1957).

Net pole potential was calculated by making appropriate deductions for inadmissible defect. Deductions by type of defect, and resulting net pole potential, are indicated in table 6.

Pole quality or value classes, described by ASA specifications (1963), are based upon pole length and diameter. Because both can be obtained from inventory data, net pole potential can be described in terms of commercial pole classes. Net noncommercial or construction poles, and net commercial poles by pole length and class, are shown in table 6.

Pulpwood potential.—All timber could be utilized for pulpwood (or other wood chip or fiber). The diameter breaking point between pulpwood and other primary product uses is likely to be highly variable. Consequently, all timber in 8-inch and larger diameter classes was considered potential pulpwood. Since the inventory data provide volume information by tree diameter classes, the volume in any range of diameter classes under consideration is immediately available. Gross pulpwood volumes (table 7) were obtained by applying cubic-foot volume tables (Myers 1963) to stand measurement data.

Visible stem quality features other than fire and lightning scars will not significantly affect volume of usable pulpwood. Fire scar will affect net volume both as an absolute reduction of volume and as a source of charred, unsuitable material. Because charred wood must be excluded from pulping operations, it is anticipated that fire-scarred trees will be long butted above the scar. Consequently, a cubic-foot volume deduction equivalent to the lower 4 feet of the merchantable stem was adopted. Lightning scars of the type recorded are similarly often accompanied by charred wood, pitch streaks, and ingrown callus bark. Stems with lightning scar were therefore considered unsuitable for pulpwood, and were culled from gross scale. These scale deduction factors were applied to the proportion of the stand affected by fire and lightning scar. Resulting scale deductions and net pulpwood volumes, by tree diameter class, are shown in table 7.

Specific, well-defined quality criteria have not been developed for pulpwood. Certain quality specifications are often used by purchasing firms, however, in defining the type of material they will accept. It seems probable that, in the future, pulpwood quality classes will be defined.

Stem characteristics that might reduce the suitability of the stem for pulping include severe crook or sweep and fork, which make handling difficult, reduce the solid wood volume of a load, and interfere with debarking or mechanical grinding. Compression wood, indicated by lean, may significantly reduce pulp yields. The cellulose content of severe compression wood has been found to be as much as 50 percent below normal (Hale et al. 1961). Excessive numbers of large knots may reduce suitability of pulpwood for grinding and reduce value for chemical pulping. Pulpwood quality classes based upon these or other stem characteristics can readily be distinguished on the basis of stem quality inventory data. The ability to stratify pulpwood into such quality classes is important in appraising suitability for specific pulping processes and handling methods.

Application to Additional Products

The preceding examples of how inventory data can be used to estimate product potential in a

Table 6.--Analysis of pole potential, per acre basis, in the example stand

Tree d.b.h. class (Inches)	Gross poles								Net poles										
	Deduction for visual defect								Noncommercial lengths		Commercial lengths and ASA classes								
	Total	Sweep	Major crook	Fork	Lean (10°+)	Lightning scar	Oversize knots	Total	10 ft. and under	15 ft.	18 and 20 ft.		25 ft.			30 ft.		35 ft.	Total[1]
											3	6	3	4	5	2	5	2	
	Number	- - - - - -	Percent	- - - - - -					- - - - - - - - - -		Number	- - - - - - - - - -							
10	13.0	1.8	0	0	1.8	0	20.0	23.6	5.0	1.2	0	2.4	0	0	1.2	0	0.1	0	9.9
12	7.4	0	4.3	0	2.2	0	26.0	32.5	2.4	1.6	.4	0	0	.2	.2	0	.2	0	5.0
14	2.1	0	5.3	0	5.3	0	30.0	40.6	.9	.2	.1	0	0	0	0	0	0	0	1.2
16	1.8	4.9	4.9	4.9	19.8	0	34.0	68.5	.3	.1	0	0	.1	0	0	.1	0	0	.6
18	2.2	10.3	0	3.4	10.1	6.7	36.0	66.5	.4	0	.1	0	0	0	0	.1	0	.1	.7
20	1.4	0	0	4.1	12.4	8.2	38.0	62.7	.2	.1	0	0	.1	0	0	.1	0	0	.5
Total	27.9								9.2	3.2	.6	2.4	.2	.2	1.4	.3	.3	.1	17.9

[1]Exclusive of volume reduction due to internal defect.

Table 7.--Analysis of pulpwood potential, per acre basis, in the example stand

Tree d.b.h. class (Inches)	Gross volume	Deduction for visual defect			Net volume[1]
		Fire scar	Lightning scar	Total	
	Cubic feet	- - - Percent - - -			Cubic feet
8	97	0.7	0	0.7	96
10	99	0	0	0	99
12	92	0	0	0	92
14	39	0	0	0	39
16	49	0	0	0	49
18	90	.8	6.7	7.5	83
20	75	.7	8.2	8.9	68
22	116	.5	5.9	6.4	109
24	95	.6	24.7	25.3	71
26	80	0	12.1	12.1	70
28	33	0	31.0	31.0	23
30	18	2.1	13.3	15.4	15
32	7	0	0	0	7
34	4	0	0	0	4
36	4	6.7	50.0	56.7	2
38	8	5.4	40.0	45.4	4
Total	906				831

[1]Exclusive of volume reduction due to internal defect.

timber stand are by no means exhaustive. If additional products command attention due to changing utilization patterns or consumer demands, the appropriate stand volumes and quality criteria can be selected from existing inventory data to estimate stand potential.

Raw material quality standards also change with time. New standards are developed to meet the needs of new products, and existing standards are revised. Most such standards will incorporate as primary grading criteria some of the stem quality features described by inventory data. Stand potential for the particular product can be reevaluated in terms of these new quality standards by selecting and applying appropriate stem quality information. Thus the inventory system provides a high degree of flexibility in meeting future product quality appraisal needs.

Comparison with Quality Observed in Felled Timber

Timber on the example area was subsequently clearcut, which provided an opportunity to compare quality evaluations made in standing and felled timber. Two-chain sample strips, which included one-fourth of the study area and contained 1,562 merchantable trees, were randomly located across the area. Each tree was felled, scaled, and graded in standard lengths for each primary product. Grading systems used in interpreting standing timber inventory data were also used in evaluating primary products in felled trees.

Timber suitability and grade distribution, judged from both inventory data and felled trees, were compared for four products (table 8). The comparisons indicate that methods of inventorying standing timber quality can provide a reasonable estimate of product potential for a range of primary products.

Inventory Information as a Basis for Decision

An inventory based on timber quality provides a wealth of information for both stand management and utilization planning. A primary objective of timber management is to produce salable raw material, within the restrictions imposed by other forest uses. A primary objective of timber utilization is to optimize the use of the resource within the limits of existing technology and product demand. Both objectives require knowledge of the physical characteristics of the stand, and the effect of these characteristics on product yield and quality. A multiproduct inventory system can provide such information.

The timber manager needs to know which type of products the stand can and should be directed toward. Although his initial concern may be with growth rates, volumes, and associated factors, of equal concern should be the occurrence of stem features that affect yield and quality for particular products. He needs to know which stem features most restrict utilization potential, and the frequency with which they occur in the stand. He needs to know how much the utilization potential for specific products is affected by stem size distribution. This type of stand information gives timber managers a basis for making management decisions. They can adequately assess the effect of a given stand treatment upon present and future product potential.

Utilization planning requires perhaps even more complete knowledge of the resource. A detailed

Table 8.--Comparison of timber quality evaluations made in standing and felled timber in the example stand

Primary product	Tree size classes included	Log grade	Quality evaluation	
			(standing)	felled
	Inches in d.b.h.		Percent of gross volume	
Saw logs	11.0 and over	3 & better	5.0	6.9
			95.0	93.1
Veneer logs	11.0 and over	1 & 2	13.7	14.2
			27.3	28.3
		([1])		57.5
Stud logs	9.0 - 22.9	1 & 2	3.5	1.0
		3	40.1	38.5
			56.4	60.5
			Stems per acre	
Commercial poles, 25 ft. and over			2.5	1.9

[1]Material graded unacceptable for the product, b[illegible] three-grade arbitrary grading systems described.
Note: "--" indicates not applicable.

Table 9.--Net primary product potential, per acre basis, in the example stand[1]

Tree d.b.h. class (inches)	Net volume by grade									Commercial poles by height class				Pulpwood volume
	Saw logs			Veneer logs			Stud logs							
	Grade 3 & better	Grade 5	Total	Grades 1 & 2	Grade 3	Total	Grades 1 & 2	Grade 3	Total	18 and 20 ft.	25 ft.	30 ft. +	Total	
	Board feet, Scribner									Number				Cubic feet
8	--	--	--	--	--	--	--	--	--	--	--	--	--	96
10	--	--	--	--	--	--	5	92	97	2.4	1.2	0.1	3.7	99
12	0	327	327	85	106	191	0	186	186	.4	.4	.2	1.0	92
14	0	158	158	7	76	83	0	52	52	.1	0	0	.1	39
16	7	186	193	46	47	93	23	67	90	0	.1	.1	.2	49
18	7	323	330	47	113	160	18	127	145	.1	0	.2	.3	83
20	17	316	333	42	72	114	0	25	25	0	.1	.1	.2	68
22	31	543	574	56	103	159	3	14	17	--	--	--	--	109
24	11	445	456	22	88	110	--	--	--	--	--	--	--	71
26	36	404	440	26	43	69	--	--	--	--	--	--	--	70
28	10	166	176	6	33	39	--	--	--	--	--	--	--	23
30	12	93	105	0	13	13	--	--	--	--	--	--	--	15
32	0	47	47	0	0	0	--	--	--	--	--	--	--	7
34	12	12	24	7	0	7	--	--	--	--	--	--	--	4
36	9	8	17	5	0	5	--	--	--	--	--	--	--	2
38	10	29	39	0	0	0	--	--	--	--	--	--	--	4
Total	162	3,057	3,219	349	694	1,043	49	563	612	3.0	1.8	.7	5.5	831

[1]Exclusive of volume reduction due to internal defect.
Note: "--" indicates not applicable.

inventory of timber and its quality is indispensable to the wood industry. Optimum utilization of timber has long been hampered by inadequate characterization of the raw material. Inventory information provides a reliable basis for interproduct comparisons in determining optimum uses.

A typical analysis of product potential in a timber stand has been described in the preceding section. To help evaluate utilization alternatives, estimated grade and net volume information for each primary product can be combined in a "product schedule" for the sampled stand. Table 9 summarizes estimated net product potential, by grade or quality class, for each diameter class of trees. Maximum potential is shown for each product. A similar schedule can also be developed for selective allocation of the timber to several or all products in order of preference. Allocation of a log for one product would then preclude its consideration for any others. This type of schedule requires prior ranking of potential products according to value or preference. Schedules such as this provide the kind of resource information needed to evaluate potential for a range of primary products and make choices between alternative products. Applied on a broad scale, such information can provide guidance for timber management planning and wood industry development.

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Barger, Roland L., and Ffolliott, Peter F.
1970. Evaluating product potential in standing timber. USDA Forest Serv. Res. Pap. RM-57, 20 p., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

The timber quality inventory described recognizes and measures the basic stem characteristics and defect features that influence quantity and quality for most primary products. Stem features measured on sample trees include form defects, scar defects, and knot or limb characteristics. Timber inventory data obtained are used in conjunction with standard methods of estimating volume, scaling, and grading to estimate:

(1) Gross volume suitable for a primary product;

(2) Probable volume reduction due to visual scaling defects, and remaining net volume suited to the product;

(3) Quality of the timber in terms of existing grading or quality classification systems.

Key Words: Forest measurement, forest products, Pinus ponderosa, timber quality inventory.

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Key Words: Forest measurement, forest products, Pinus ponderosa, timber quality inventory.

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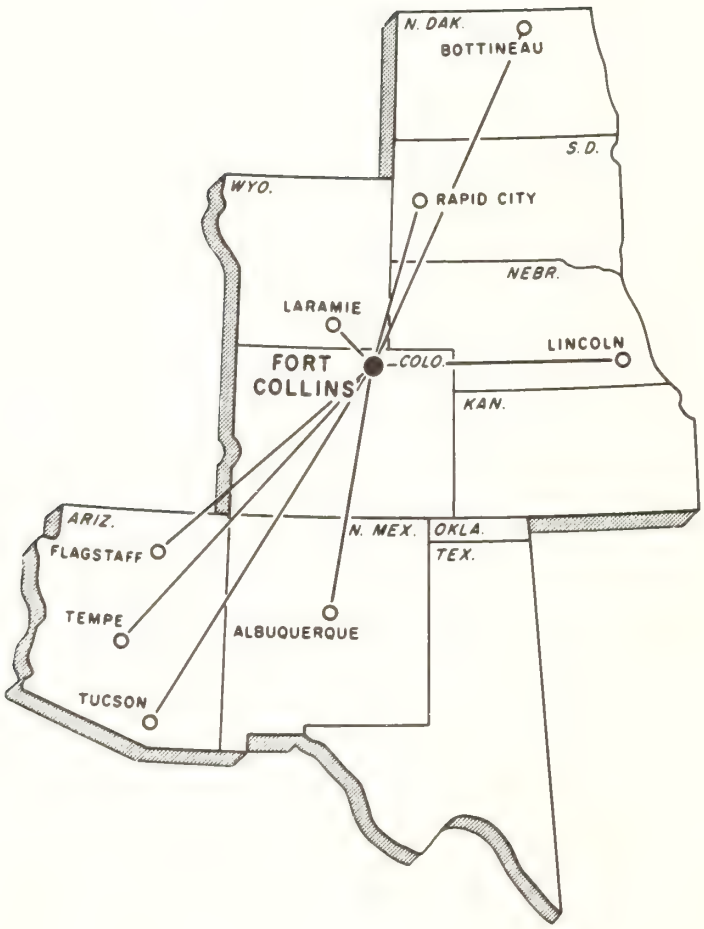
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cone crops of ponderosa pine in central arizona including the influence of abert squirrels

M. M. Larson
Gilbert H. Schubert

U.S.D.A. Forest Service
Research Paper RM-58
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Rocky Mountain Forest and Range Experiment Station
Forest Service U.S. Department of Agriculture

ABSTRACT

Large, vigorous, isolated ponderosa pines were the best cone producers in terms of seed quantity, quality, and frequency of bearing in the Southwest. Large cone crops occurred in 3 years out of 10. Trees 28 to 40 inches in diameter averaged 218 to 446 cones each per year. In contrast, trees 12 to 20 inches in diameter averaged less than 22 cones. The largest crop produced was 7,521 cones per acre in 1960, when 59 percent of the trees bore more than 100 cones each. Abert squirrels reduced the 10-year cone production by one-fifth. Conelet-bearing twigs clipped by squirrels provide a basis for predicting cone crop size.

Key words: Pinus ponderosa, conelets, cones, Abert squirrel

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Cone Crops of Ponderosa Pine in Central Arizona, Including the Influence of Abert Squirrels

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[1] Central headquarters maintained at Fort Collins, in cooperation with Colorado State University; research reported here was conducted at Flagstaff, in cooperation with Northern Arizona University. Larson is now with the Forestry Department, Ohio Agricultural Research and Development Center, Wooster, Ohio.

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Cone Crops of Ponderosa Pine in Central Arizona, Including the Influence of Abert Squirrels

M. M. Larson and Gilbert H. Schubert

Introduction

Large quantities of seed are needed to maintain or increase productivity on about 7.5 million acres of commercial ponderosa pine (Pinus ponderosa Laws.) timberland in Arizona and New Mexico. Although ponderosa pines produce enough seed, time intervals between good crops and large differences in cone production between individual trees determine the amount of seed produced in an area. Since natural regeneration is still relied on to restock large areas, seed supply is a matter of primary importance.

This Paper reports on a 10-year investigation of the cone crops of ponderosa pine, and the influence of Abert squirrels (Sciurus aberti aberti Woodhouse) on these crops. In the study on the Fort Valley Experimental Forest, we determined the types of trees bearing cones, size and frequency of cone crops, seed dissemination, and the detrimental influence of the seed-eating and twig-clipping activities of the Abert squirrel. We also found that the abundance of conelets [2] on clipped twigs indicates the size of the ensuing seed crop.

[2] *In this paper the term "conelet" refers to ovulate strobili from the time of their appearance in late spring until their fertilization the following spring. After fertilization, the term "cone" is used. Clipped twigs may have both 1-year-old conelets and new flower buds. Only the 1-year-old conelets were counted, since new flower buds could not be distinguished at this stage from vegetative buds.*

Detailed descriptions of flowering and cone development of ponderosa pine have been reported by Roeser (1941) and Gifford and Mirov (1960). Long-term studies of cone production were reported for ponderosa pine in California (Fowells and Schubert 1956), in Montana (Boe 1954), and in Washington (Daubenmire 1960). In the Southwest, Pearson (1912, 1923, 1950) identified the types of trees that bear good cone crops, and indicated the kind and number of trees needed to provide an adequate seed supply for regeneration.

Adequate stands of natural regeneration are infrequent; seed supply may be a limiting factor at times, but our knowledge is inadequate. Abert squirrels are known to destroy large numbers of cones (Keith 1965), but a long-term quantitative evaluation of damage has never been made. This study revealed that squirrel impact can indeed be substantial, even in periods of low populations.

Conduct of the Study

Experimental Area

The study was conducted on a 10-acre plot in the G. A. Pearson Natural Area near Flagstaff. The virgin stand contained 253 trees over 12.0 inches in diameter breast high (d.b.h.). The trees averaged 22.7 inches d.b.h. and were mature and overmature (fig. 1). Twelve trees that died during the study were excluded from the analysis.

Figure 1.--Ponderosa pines on the G. A. Pearson Natural Area of the Fort Valley Experimental Forest.

There were very few trees 8 to 12 inches d.b.h. Dense patches of saplings and small poles of 1919 origin occupied most of the ground space not covered by crowns of the larger trees.

The site index is about 85 feet at base age of 100 years. The plot is nearly level, with a slight south-facing aspect. The silty clay loam soil was derived from basalt and is nearly neutral in pH. Precipitation averages about 23 inches annually. The wettest months are July and August. The temperature ranges from a mean maximum of 88.2° F. in July to a mean minimum of -11.2° F. in January. The hottest and coldest temperatures were 96° F. and -37° F.

Tree Classifications

All trees were classified as to age-vigor (Thomson 1940), tree position, dominance, and squirrel damage (table 1). The diameter of each sample tree was measured in the fall of 1954 and in spring of 1965 for a 10-year growing period.

Cone Counts

Three classes of cones were collected and counted in each of the 10 crop years. The first class consisted of immature cones cut by squirrels beginning about mid-June and ending in late October (fig. 2). These collections and counts were made at about monthly intervals. Cones cut by squirrels were easily identified since the green cone scales were chewed off and the seeds eaten. No cones or seeds are stored by Abert squirrels.

The second class consisted of normal undamaged cones. These cones were collected and counted in the spring following seed fall. Since not all cones are released during the winter months, additional collections were made during the summer with a final collection prior to the drop of the next crop.

Table 1.--Tree classifications and descriptions of subclasses

Tree classifications	Description
Age-vigor[1]	
Age II	Young "blackjacks" of sawtimber size
Age III	"Intermediates" or young "yellow pines" (mature)
Age IV	Old "yellow pines" (overmature)
Vigor A	Full vigor, crown 55 to 70 percent of tree height
Vigor B	Good to fair vigor, crown 35 to 55 percent of tree height
Vigor C	Fair to poor vigor, crown 20 to 35 percent of tree height
Vigor D	Very poor vigor, crown less than 20 percent of tree height
Tree position	
Isolated	Trees isolated, free to grow on all sides
Open	Open grown trees but near a group of trees
Marginal (border)	Marginal trees growing on the edge of a group
Interior	Interior trees growing inside a group
Tree dominance	
Dominant	Trees with crowns extending above the general crown level
Codominant	Trees with crowns forming the general crown level
Intermediate	Trees shorter but crowns extend into the general crown level
Suppressed	Trees with crowns entirely below the general crown level
Squirrel damage	
None	No visible crown damage
Light	Some twig cutting apparent but crowns dense
Medium	Moderate twig cutting, noticeable crown thinning
Heavy	Crown very thin due to twig cutting

[1]Based on Keen's Tree Classification as modified for the Southwest by Thomson (1940). Age class I "young blackjacks" less than 12 inches diameter were not included in the study.

Figure 2.--Ponderosa pine cones with scales and seed removed by Abert squirrels. From left to right, cones were collected in 1956 on June 19, July 9, August 2, and October 23, respectively.

Most trees shed all except insect-infested cones within 1 year. Although four trees consistently retained a few cones for more than 1 year, they introduced an insignificant error into yearly totals.

The third class consisted of insect-infested cones. These cones were usually small, deformed, pitchy, and contained exit holes, principally of the ponderosa pine cone beetle (Conopthorus scopulorum Hopk.). These insect-damaged cones often persisted on the tree for more than 1 year, so the cone year could not be determined precisely.

All three classes of cones were credited to the tree from which they appeared to have fallen. Crown shape, tree lean, and prevailing wind direction were all considered in assigning cones to their probable source tree. This tree assignment was also facilitated by the cone crop rating of heavy, medium, light, or none given each tree prior to cone release.

Twig Counts

Twigs (branch tips) clipped by Abert squirrels were counted in May or early June of each year (figs. 3, 4). These clipped twigs bore distinctive tooth marks on the cut end, which made them easy to distinguish from the few wind-broken twigs found in the area. Because twigs fell directly beneath the parent tree, they were easy to credit properly. Very few twigs were clipped by the squirrels from late May to early December.

Figure 3.--A ponderosa pine twig (lateral shoot or branch tip) with a conelet (unfertilized female strobilus), and a peeled branch section. Abert squirrels first cut off the twig from the branch section, then eat the tender inner bark.

Figure 4.--Crown of a ponderosa pine tree, 16 inches d.b.h., heavily damaged by Abert squirrels. This tree was severely clipped every year during the 10-year study.

Prediction of Cone Crops

Each twig clipped by squirrels was examined and the number of 1-year-old conelets recorded (fig. 3). These conelets would have matured by October. It was assumed that Abert squirrels clip twigs without regard to the presence of conelets, and that similar crown areas were attacked each year. Most twigs appeared to be cut from the upper part of the crowns. The ratio of conelet-bearing to total clipped twigs was then related to the number of cones produced that fall.

Seed Counts

Fifty seed traps, each 3.3 feet square (1/4 milacre), were randomly located on the plot in 1956 (fig. 5). Seeds caught in the traps were counted each of the 10 years. Seed quality was determined in some years by floating off the hollow seeds in acetone. Germination tests were made on three crops. The time of seed fall was determined for the 1965 crop by counting the trapped seed frequently after the cones started to open.

Results and Discussion

Types of Trees Bearing Cones

The largest trees produced the most cones. Trees 36 to 40 inches d.b.h. averaged 446 cones per tree per crop, compared to six cones produced by trees 12 to 16 inches d.b.h. (table 2). Tree diameter accounted for about 94 percent of the variation in cone production (average annual cone production per tree = -299.82 + 18.19 d.b.h.). Trees under 24 inches d.b.h. at Fort Valley averaged less than 100 cones per crop, which was similar to the results obtained for ponderosa pine in California (Fowells and Schubert 1956). However, trees 36 to 40 inches d.b.h. produced about twice as many cones as California trees in the same size class.

Largest cone crops occurred on trees that were free to grow on all sides (table 2). These trees, classified as "isolated," averaged 274 cones per crop compared to 42 for "interior" trees within a group. Pearson (1912, 1923) also noted the superior

Figure 5.--
A 1/4-milacre trap used to sample seed fall.

Table 2.--Distribution of trees and cone production by several classification criteria on the 10-acre Fort Valley Experimental Forest plot during the 10-year period, 1956-65

Classification	Trees	Total cones produced	Crops with per-tree average greater than:		Average annual cone production per tree
			5 cones	100 cones	
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DIAMETER (Inches)					
12-16	34	1,922	2.1	0.1	6
16-20	51	10,461	4.5	.6	21
20-24	55	41,238	7.7	2.1	75
24-28	62	86,485	8.7	3.6	139
28-32	26	56,791	9.3	4.4	218
32-36	11	33,704	9.7	5.7	306
36-40	2	8,929	10.0	6.5	446
AGE-VIGOR					
II D	13	1,915	2.4	.4	15
C	37	8,859	4.4	.7	24
B	34	13,149	5.0	1.1	39
A	5	2,363	6.2	1.4	47
III D	28	15,246	6.6	1.8	54
C	47	56,445	8.1	3.0	120
B	36	63,313	8.7	3.8	176
A	7	12,911	9.7	4.4	184
IV D	4	2,789	8.2	2.0	70
C	18	22,565	8.1	3.2	125
B	10	31,011	9.8	5.6	310
A	2	8,964	10.0	6.5	448
STAND DENSITY					
Interior	50	21,059	5.5	1.2	42
Marginal	135	121,885	6.8	2.2	90
Open	49	77,395	7.9	3.5	158
Isolated	7	19,191	8.3	5.0	274
SQUIRREL DAMAGE					
Heavy	25	13,470	—	--	54
Medium	48	47,632	--	--	99
Light	156	158,692	--	--	102
None	12	19,736	--	--	164
TREE DOMINANCE					
Suppressed	30	3,061	3.4	1.7	10
Intermediate	53	22,546	5.3	1.2	43
Codominant	67	58,932	7.3	2.4	88
Dominant	91	154,991	8.4	3.8	170
Total or Average	241	239,530	—	--	99

Note: "--" indicates negligible.

cone productivity of isolated trees over those growing within a stand. Due to their greater numbers, "marginal" trees around the exterior of stands produced the greatest quantity of cones.

Dominant trees bore the most cones (table 2). They rate this distinction on both a stand and on individual-tree basis. Since the dominant trees were also largest in diameter, part of this extra

cone production must be related to their superior size. For example, when the effect of tree diameter was held constant in a least-squares analysis, the differences in cone production between dominance classes was less pronounced. In an even-aged stand, dominance may have a much greater independent effect than in an all-aged stand where shorter trees on the edge of a group often have large cone-bearing crowns.

Trees with the least amount of squirrel damage bore the most cones (table 2). Trees with undamaged crowns produced over three times as many cones per crop as trees with heavy crown damage. Nearly 65 percent of the trees had light squirrel damage, and they produced 66 percent of the 10-year total.

Cone production varied significantly among age-vigor classes (table 2, fig. 6). The largest crops per tree were borne by the oldest, most vigorous trees; thus the older "yellow pines" (age class IV) of good vigor were excellent producers. The poorest producers were age class II "blackjack" trees and trees of poor vigor. On a stand basis, trees classified IIIA and IIIB produced the most cones, partly due to their greater occurrence. Although ponderosa pines can produce cones at age 16 and continue to produce at age 350 (Curtis 1955), it is the large, mature trees that produce the heavy crops.

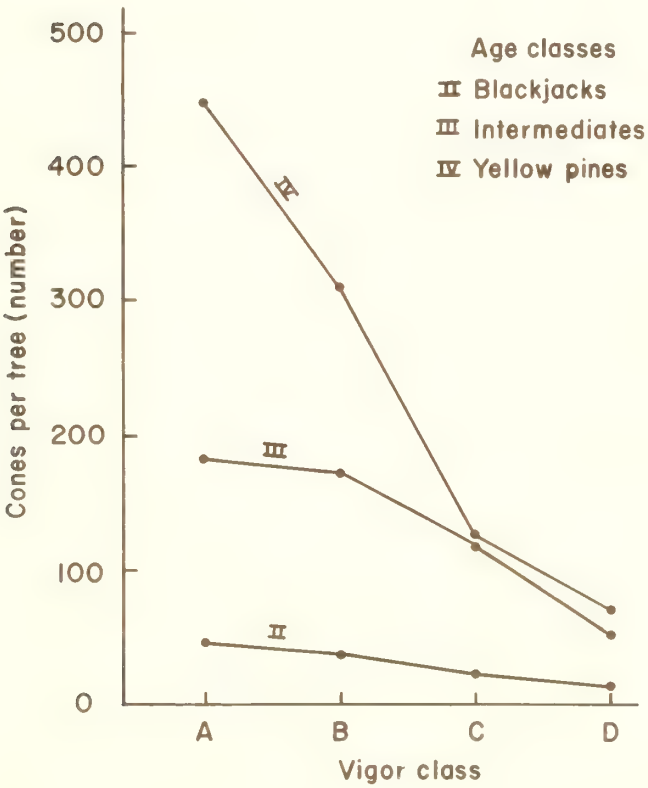

Figure 6.--Effect of vigor on average annual cone cone production per tree for trees in each age class.

The record total 10-year production by an individual tree was 5,677 cones. This tree, 33.6 inches d.b.h. and age-vigor class IVB, also produced the most cones in a single year, 1,887 in 1960.

Size of Annual Cone Crops

The annual production of undamaged cones varied from 80 to 7,046 per acre (table 3). The greatest number of cones, a "bumper" crop, was produced in 1960. Based on an average of 37 good seeds per cone, this "bumper" crop was equivalent to 263,000 seeds per acre (about 22 pounds). Data are unavailable for a direct comparison with the 1918 seed crop, but based on Pearson's (1950) estimate of a seed to seedling ratio of 100:1, the 1918 crop may have been up to four times greater than the 1960 seed crop.

Cone crops in 1956 and 1965 were rated as large (table 3), but were about half the bumper crop in 1960. Cone crops were small in 5 of the 10 years.

Frequency of Good Cone Crops

Large ponderosa pine cone crops have been observed on the Coconino and Kaibab National Forests in 1913, 1918, 1927, 1936, 1942, 1945, 1954, 1956, 1960, and 1965. Therefore, during this 52-year period, large cone crops occurred at intervals of about 5 years.

Frequency of Cone Bearing by Individual Trees

During the 10-year period, nearly all trees produced at least one cone; only 6 percent of the trees produced fewer than 100 cones. On the other hand, 65 percent of the trees produced at least one crop that exceeded 100 cones, and 95 percent had at least one crop that exceeded five cones. Forty trees (16.6 percent) had five or more crops that exceeded 100 cones per tree, while seven trees produced eight such crops.

Table 3.--Annual ponderosa pine cone production per acre, number of trees bearing more than 5 and more than 100 cones, and number of cones destroyed by Abert squirrels on the 10-acre Fort Valley plot

Year	Total cones per acre	Cones destroyed by squirrels		Undamaged cones	Trees bearing more than:		Cone crop rating[1]
					5 cones	100 cones	
	Number	Number	Percent	Number	- - Percent - -		
1956	4,503	870	19.3	3,633	83	52	Large
1957	2,675	806	30.1	1,869	85	23	Medium
1958	741	194	27.5	547	67	5	Small
1959	316	236	74.7	80	36	2	Small
1960	7,521	475	6.3	7,046	90	59	Bumper
1961	936	3	.3	933	65	10	Small
1962	464	310	66.9	154	54	2	Small
1963	1,792	1,137	63.5	655	56	20	Small
1964	1,691	648	38.4	1,043	64	17	Medium
1965	3,730	403	10.8	3,327	78	48	Large
Average	2,437	508	20.9	1,927	68	24	

[1]Based on production of undamaged cones as follows: small, less than 1,000; medium, 1,000 to 3,000; large, 3,000 to 6,000; bumper, greater than 6,000.

The greatest number of trees bore cones during the 1960 bumper seed year. In that year, 90 percent of the trees bore at least five cones and 59 percent bore at least 100 cones (table 3).

Frequency of cone bearing was strongly correlated with tree diameter (table 2). The correlation coefficient of frequency to diameter was 0.94 for crops exceeding five cones per tree and 0.99 for those exceeding 100 cones. Individual trees over 28 inches in diameter averaged 9.7 crops over five cones and 5.5 crops over 100 cones during the 10-year period. In contrast, trees under 20 inches d.b.h. averaged only 3.3 crops over five cones and 0.4 crop over 100 cones.

Frequency of cone bearing also increased with increased growing space (table 2). Isolated trees had the greatest number of crops, while interior trees had the least.

Comparisons by dominance classes showed that dominant trees bore cones more frequently than other classes. Although a few intermediate and suppressed trees bore cone crops exceeding 100 cones per tree, the low frequency rate indicates that these trees are poor cone producers.

Cone crop frequency increased with age, but decreased with decreased tree vigor (table 2). In general, IVA trees produced a large crop most frequently and IID trees the least. Only IVA and IVB trees produced large crops over 50 percent of the time. None of the class II "blackjacks" contributed much to the three large cone crops during the 10-year period.

Cones Destroyed by Squirrels

The proportion of cones cut by Abert squirrels varied significantly during the period 1956-65 (table 3). The number of cones cut varied from 3 per acre in 1961 to 1,137 in 1963. The proportion of the cone crop cut by squirrels varied from 0.3 percent in 1961 to 74.7 percent in 1959.

The number of cones cut by squirrels was not closely related to the size of the total crop. The medium cone crop in 1963 was reduced to a small crop when squirrels cut over double their yearly average. In general, a higher proportion of the crop was cut during poor than during good seed years. Heavy losses of ponderosa pine cones to tree squirrels have been reported in Colorado (Roeser 1941), Idaho (Squillace 1953), and California (Fowells and Schubert 1956).

Abert squirrels reduced the total 10-year cone production at Fort Valley by 21 percent (table 3). In addition, many conelets and flower buds were destroyed when squirrels clipped twigs for food. Although the loss by twig clipping averaged only 22 conelets per acre, it raised the total destroyed by an extra 1 percent. Squillace (1953) reported

a 9 percent loss of conelets due to twig clipping by squirrels in Idaho.

Cone cutting by squirrels was strongly correlated ($r = 0.980$) with number of cones per tree. The largest trees produced and lost the most cones (fig. 7). Although small trees lost a higher proportion of their cones, the large trees, with more cones available, lost the most.

Cone cutting varied widely among trees. Some trees lost no cones while some lost 80 percent. The highest number cut from a single tree was 1,293 cones in 1964. Several trees lost over half of their total 10-year production to squirrels, while other trees produced several thousands of cones and lost less than 10 percent.

No reason was found for this preference of cones from one tree to another.[3] In this study, the portion of cones lost to squirrels was not affected by age-vigor, ground position, dominance, or squirrel damage to crowns. Tree nutrition may be a factor. Asher (1963) reported that squirrels preferred the cones of fertilized slash pine trees over those of unfertilized trees.

Cone cutting can be prevented by placing an 18-inch-wide metal band around the trunks of seed trees (Tackle 1957, Krugman and Echols 1963). The bands prevent the squirrels from climbing the trunks, but the tree crown must also be at least 7 feet from that of unbanded trees. Control of squirrel populations by hunting has been of limited success. Goshawks may be a predator of squirrels in some areas (Reynolds 1963).

[3] *Ralph A. Read found that jackrabbits seemed to prefer trees from certain seed sources in his provenance study. (Unpublished data on file at Rocky Mt. Forest and Range Exp. Sta., U. S. Forest Serv., Lincoln, Nebr.)*

Cones Infested by Insects

From 1958 through 1964, 3,404 cones were found to infested with insects. Insect-infested cones were not included in the yearly totals because they often persist for more than 1 year. They would have increased the total number of cones by

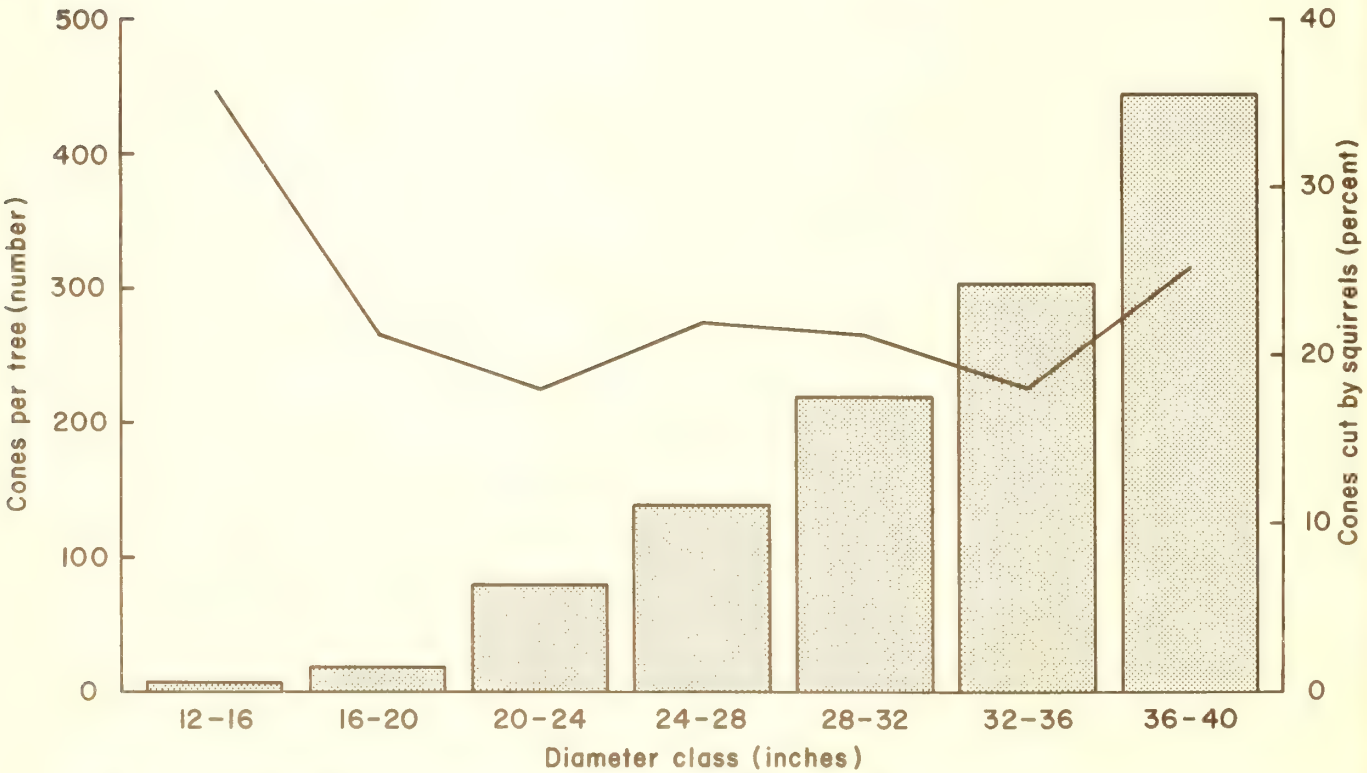

Figure 7.--Average yearly cone production per tree (bars) and the average percentage of cones cut by Abert squirrels (line) for trees in each diameter class.

Table 4.--Annual ponderosa pine seed production, estimated seed production, and twig cutting by Abert squirrels on the 10-acre Fort Valley plot

Year	Total seed in traps[1]	Filled seed[2]	Estimated total seed production per acre	Twigs cut by squirrels (per acre)			
				Total	With conelets		Conelets per twig
	Number	Percent	Number	Number	Number	Percent	Number
1956	1,331	--	106,480	286	31	10.7	1.6
1957	688	--	55,040	605	37	6.1	1.7
1958	16	--	1,280	595	5	.9	1.3
1959	13	--	1,040	357	2	.6	1.4
1960	3,292	81	263,360	231	23	10.0	1.7
1961	69	45	5,520	592	12	2.0	--
1962	37	22	2,960	140	3	2.2	1.7
1963	271	17	21,680	125	5	4.2	1.7
1964	185	10	14,800	154	10	6.2	1.7
1965	1,568	65	125,440	136	10	7.0	1.8
Average	747	40	59,760	322	13.8	5.0	1.6

[1]Fifty traps, each 3.2 x 3.2 feet or 1/4 milacre.
[2]Seeds placed in acetone and "sinkers" counted as filled.
Note: "--" indicates not measured.

2.5 percent, however. Fifteen of the 241 study trees accounted for 63 percent of the total infested cones. These "insect preferred" trees were characteristically dominant or open grown, and averaged 28 inches d.b.h., 5 inches larger than the average for the plot.

Larvae of the cone beetle (Conopthorus scopulorum Hopk.) were found in infested cones, but other cone insects may also have been present. Pearson (1950) reported that cone beetles are especially serious pests in the lower portions of the pine type, where they have completely destroyed cone crops. A method to control cone beetles on ponderosa pine has not been developed, but the systemic insecticide "bidrin" implanted in trunks gave good control of cone insects in slash pine (Merkel 1969).

Twig Cutting by Abert Squirrels

Squirrels clipped from 125 to 605 twigs per acre annually (table 4). It is not known how many twigs were available for clipping. Relatively few were clipped during the final 4 years of the study.

Trees with "heavy" crown damage in 1956 continued to be heavily clipped throughout the study. These trees lost an average of 33 twigs per year, compared to four twigs per year for trees with little to no crown damage. Twig clipping by squirrels was similar among trees with respect to tree position, dominance, diameter, and age-vigor class.

The most severe twig clipping sustained by an individual tree totaled 1,869 twigs for the 10-year period. This tree, 23.1 inches d.b.h. and of age-vigor class IIIC, lost 656 twigs in 1959, a record number during a single year. The squirrel population at Fort Valley was very high from 1940 to 1945 (Keith 1965), and Pearson (1950) observed that it was not unusual to find as many as 1,000 twigs under a single tree. Pearson (1950) also noted decreased diameter growth of individual trees severely damaged by squirrels. During the present study, one tree just outside the plot boundary died after repeated heavy twig clipping by squirrels.

Every tree in the study area was "tasted" by squirrels at least once during the 10-year period. Occasionally, individual trees suffered heavy twig clipping in 1 year, but then were virtually ignored in other years. Repeated clipping of the same tree year after year was the rule, however: one-third of the total twigs clipped during the study came from only 13 trees.

One might expect the number of twigs clipped each year would be related to the number of cut cones, and that these yearly cuttings of twigs and cones would indicate trends in the size of the squirrel population of the area. However, the number of clipped twigs (table 4) was not related to the number of cut cones (table 3) and neither of these

may accurately reflect the size of the current squirrel population. The twigs are clipped during the winter and spring, while the cones are cut during the summer and fall. Individual Abert squirrels range over about 18 acres during the summer but only 5 acres during the winter (Keith 1965). Thus, the squirrel population of the surrounding area would largely determine the degree of cone and twig clipping within the 10-acre study plot. A high winter mortality of a large squirrel population could result in many clipped twigs but few cut cones the following summer. Also, the area was open to squirrel hunting each fall.

The percentage of cut twigs with one or more conelets ranged from 0.6 to 10.7 percent (table 4). The number of conelets per conelet-bearing twig usually averaged 1.6 to 1.8.

Prediction of Size of Cone Crops

The percentage of twigs with conelets found each spring was related to the size of the cone crop that followed (fig. 8). When 7 percent or more of the twigs bore conelets, large cone crops followed, whereas a low percentage of conelet-bearing twigs always preceded small crops. The approximate number of cones per tree can be estimated from figure 8 by dividing the number of cones per acre (Y-axis) by the number of trees per acre bearing cones. In our study, an average of 25 trees per acre bore cones during the 10-year period.

In the construction of figure 8, the number of cones cut by squirrels was included in the total cones, since yearly depredations vary widely. When only the number of cones that survived to maturity

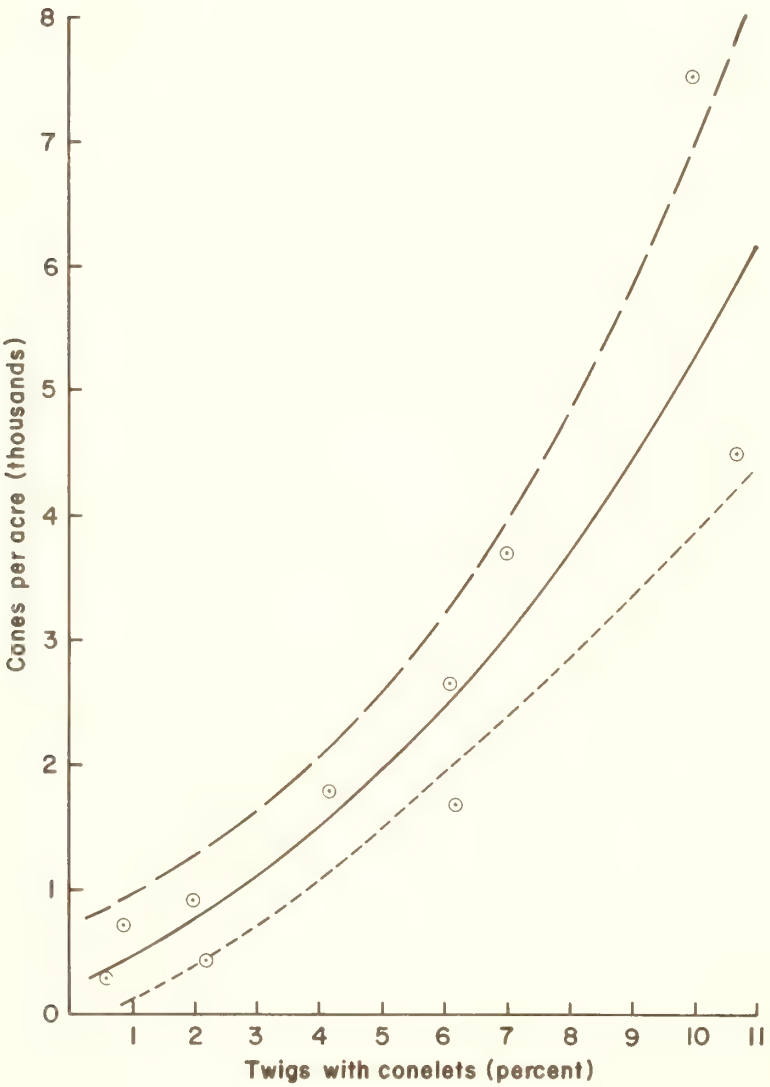

Figure 8.--Relationship between total cone production per acre and the percentage of twigs with conelets found during the spring preceding the maturation of cones. The calculated regression line is $Y = (16.41 + 5.64x)^2$, $F = 47.41^{**}$. *Dashed lines indicate upper and lower 95 percent confidence limits.*

were considered, the relationship with the yearly percentage of twigs with conelets was less close.

Prediction of seed crops by counting conelets (ovulate strobili) on selected branches or trees has been attempted with larch (Roe 1966), longleaf pine (Shoulders 1967), loblolly pine (Trousdell 1950), pinyon (Little 1939), Douglas-fir (Allen 1941, Roeser 1942), red pine (Lester 1967), and ponderosa pine (Roeser 1941, Maguire 1956). Results ranged from very good to poor. In general, crop failures and light crops were predicted with considerable success, but predicted heavy crops often failed because the conelets died before they matured.

Mortality of conelets is greatest during the first growing season after emergence; losses average 64 percent in ponderosa pine (Roeser 1941), 60 percent in red pine (Lester 1967), and 87 percent during one season in slash pine (Merkel 1961). Unfavorable weather and insects were the major causes of conelet mortality. It appears that large crops can be accurately predicted only when conelets are counted after the first growing season (as in this study) and when cone cutting by squirrels is low.

Some investigators have predicted cone crops on the basis of temperature. For example, Maguire (1956) found that above-average temperatures in April and May stimulated flowering the following spring, and Daubenmire (1960) also reported that above-average temperature during the summer that flower initials are formed improved cone production 2 years later. No attempt was made in our study to relate weather data with cone production.

Correlations

The 10-year cone production of individual trees was significantly correlated with the percentage of twigs with conelets ($r = 0.429^{**}$), although the r^2 is only 18 percent. The following measurements were not significantly correlated at the 5 percent level: total cones vs total twigs; total twigs vs percent twigs with conelets; total twigs vs percentage of cones cut by squirrels; percent twigs with conelets vs percentage of cones cut by squirrels; and total cones vs percentage of cones cut by squirrels.

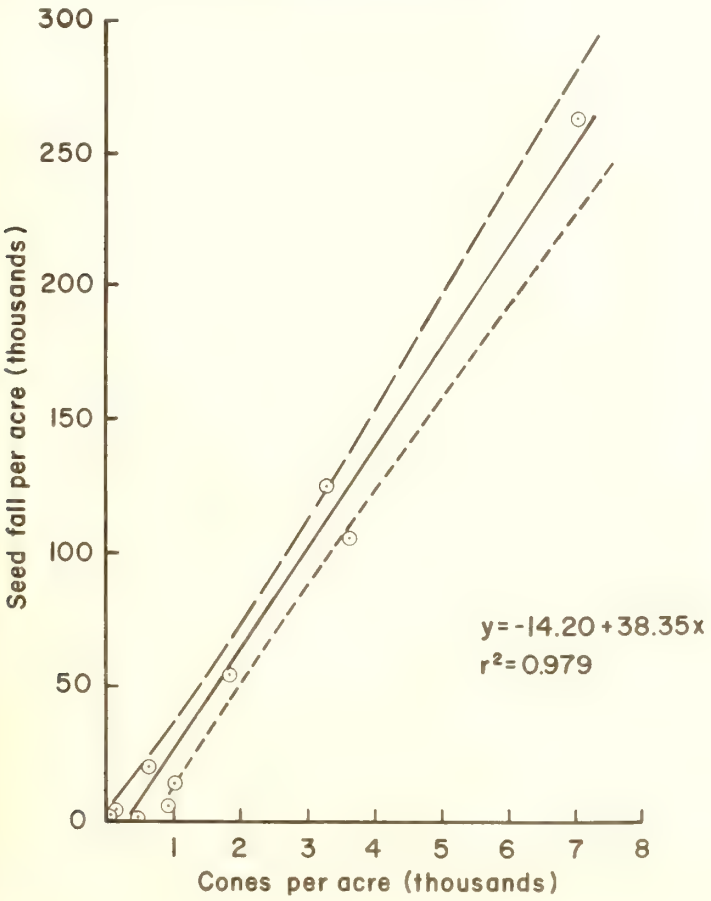

Figure 9.--
Relationship of seed fall per acre (estimated from seed found in seedtraps) to production of undamaged cones per acre.

Seed Dissemination

Seed fall.—Seed fall per acre ranged from 263,360 in 1960 to only 1,040 in 1959 (table 4). Seed fall exceeded 100,000 seeds per acre when production of undamaged cones exceeded 3,000 per acre. A good linear relationship was found between the yearly seed fall and the number of undamaged cones produced ($Y = -14.20 + 38.35x$ with an $r^2 = 0.979$) (fig. 9). The relation between seed fall sample and the cone estimate in California was curvilinear when the number of cones was estimated on standing trees (Fowells and Schubert 1956).

The annual seed fall per acre was also related to the percent of conelet-bearing twigs ($r = 0.801$). The regression equation is $Y = -33.732 + 18.736x$, but since the standard error of estimate ($S_{y \cdot x}$) is high (53,776), it should not be used to predict seed fall.

No information was obtained on seed flight and distribution. We know, however, that ponderosa pine trees do not effectively disseminate seeds over extensive areas (Fowells and Schubert 1956). Siggins (1933) measured the rate of fall of various lots of seed of several species in still air. From these rates of fall and an assumed tree height, the flight of seeds for various wind velocities can be calculated. For example, ponderosa pine seeds fall 15.2 feet per second in still air. Seed, falling 100 feet with a uniform wind of 10 miles per hour, would travel, on the average, about 294 feet horizontally. Barrett (1966) has recommended that ponderosa pine clearcuts should not exceed 5 chains in width.

The study area was well stocked with trees, but few, if any, seedlings became established during the 10-year study. The heavy seed fall of 1960 resulted in a literal carpet of new seedlings the following summer, but nearly all died during the ensuing winter and spring drought.

Seed quality.—The largest cone crops produced the best quality seeds. The large crops in 1960 and 1965 produced seeds that were at least 65 percent filled, compared to 10 to 45 percent for the smaller crops (table 4). For the 1965 crop, 72 percent of the seeds that fell before December 6 were filled, compared to only 54 percent for seeds that fell after that date. The average weight of filled early- and late-fallen seeds was the same (37 mg.), and germinated similarly (63 and 64 percent, respectively). In 1956, 91 percent of filled seeds germinated when planted in a greenhouse.

In California, the percentage of filled ponderosa pine seeds was also highest (72 to 79 percent) during years of heavy cone crops (Fowells and Schubert 1956). Other researchers have also noted that the first-fallen seeds are the most viable in this species (Squillace and Adams 1950, Curtis and Foiles 1961, Fowells and Schubert 1956). Curtis (1955) noted that ponderosa pine seeds from trees 60 to 160 years old in the northern Rocky Mountains were more viable than seeds from younger or older trees. Pearson (1923) found no differences in seed viability for trees 16 to 34 inches in diameter.

Time of seed fall.—Seeds in the seed traps were counted frequently as the 1965 crop fell, except when the traps were under snow. By October 26, only 0.5 percent of the current seed crop had fallen. By December 6, 64 percent had fallen, and by April 1, 1966, 95 percent of the total crop had fallen. Hence, nearly all seeds were shed in time to germinate the following summer. However, 26 percent of the 1960 seed crop fell between July 1 and September 26, 1961. No reason for this late seed fall is known, but similar occurrences may explain the occasional "delayed" germination of seed crops reported by Pearson (1950). More observations are needed to determine variations in the time of seed fall in the Southwest.

In California, Fowells and Schubert (1956) noted that strong, dry winds hastened seed fall, and that the majority of ponderosa pine seeds usually fell during October and November. In 1 year, however, these authors observed that 33 percent of the seed crop fell between November and August. In Idaho, seed fall from a heavy cone crop was 52 percent complete by September 15, and 90 percent complete by October 22 (Curtis and Foiles 1961).

Number of seeds per cone.—Cones averaged 31 seeds each, and the number of seeds per cone increased with the size of the cone crop. The five smallest cone crops, each less than 1,000 cones per acre, averaged only 14 seeds per cone compared to 33 for the five crops that exceeded 1,000 cones per acre. This is considerably less than the 70 seeds per cone reported for ponderosa pine in California (Fowells and Schubert 1956) and 64 to 92 seeds per cone for this species in Idaho (Curtis and Lynch 1957).

Silvicultural Considerations and Conclusions

Healthy, mature trees with exposed crowns and of large diameter are usually the best seed producers. Past fruitfulness, as indicated by the accumulation of old cones under a tree, is a good criterion for choosing seed trees (Downs 1947, Fowells and Schubert 1956, Pearson 1950). Also, cone production is a highly heritable trait (Matthews 1963). Therefore, the best trees to retain for seed production are those which:

1. Are about 24 to 28 inches in diameter.
2. Are dominant or free to grow.
3. Have a vigor class rating of A or B.
4. Are free of disease or heavy squirrel damage.
5. Show evidence of having produced good cone crops.
6. Have straight boles.
7. Have medium to small branches.

The number of seed trees needed to insure an adequate seed supply for regeneration cannot be stated with certainty. The periodicity of cone production was amply demonstrated during the present study. Large yearly variation in cone losses to squirrels and insects, and the consumption of seed on the ground by rodents and birds, make it almost impossible to determine what an "adequate" seed supply is. After seeds germinate, drought and frost heaving can wipe out the entire seedling crop (Larson 1960, 1961).

In the Southwest, Pearson (1950) somewhat arbitrarily recommended that six seed trees 18 inches d.b.h. or larger be left per acre after harvest. Results of the present study indicate that, if these trees are chosen with care, they could average 200 cones per year over a 5-year period. The total seed fall would be about 144,000 seeds, and of these, an estimated 72,000 (50 percent) would be sound. Pearson (1950) concluded that one seed in 100 survives to produce a seedling on moderately favorable sites. Thus, a final stocking of 720 trees per acre would result. It must be emphasized, however, that reliable guidelines must await the results of several harvest cuts.

Presently, planting seedlings on prepared sites is a much more certain way to establish new stands in the area adjacent to the Fort Valley Experimental Forest (Heidmann 1963). Another advantage of planting is that new stands may be genetically superior to those obtained from natural regeneration, if seed sources of planting stock are properly selected.

Abert squirrels are extremely destructive to cone crops. These squirrels destroyed more than 20 percent of the total 10-year cone production. Also, we observed that only the largest and best cones were taken by squirrels. Their twig-clipping activities are less destructive, and the loss of conelets was not considered serious. The squirrel population during the study was rated low, however; high squirrel populations may well preclude an adequate seed supply for natural regeneration in all but "bumper" crop years.

Cone losses to insects were not serious during the study.

The size of cone crops was closely related to the number of conelet-bearing twigs clipped by squirrels the previous winter and spring seasons. Therefore, the relative size of crops can probably be predicted on any area where squirrels clip twigs. Conelets abort mostly during the first growing season rather than during the following dormant season (Roeser 1941). Thus, the size of the conelet crop in October may accurately reflect the size of the cone crop a year later. Squirrels clip twigs after October, however, so the abundance of conelets must be determined from branch samples or by use of binoculars. Prediction of crops 1 year in advance, if reliable, would greatly aid in planning for seed-collection programs and site-preparation measures to obtain natural regeneration.

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Agriculture --- CSU, Ft. Collins

Larson, M. M., and Schubert, Gilbert H.
1970. Cone crops of ponderosa pine in central Arizona, including the influence of Abert squirrels. USDA Forest Serv. Res. Pap. RM-58, 15 p., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

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Key words: Pinus ponderosa, conelets, cones, Abert squirrel

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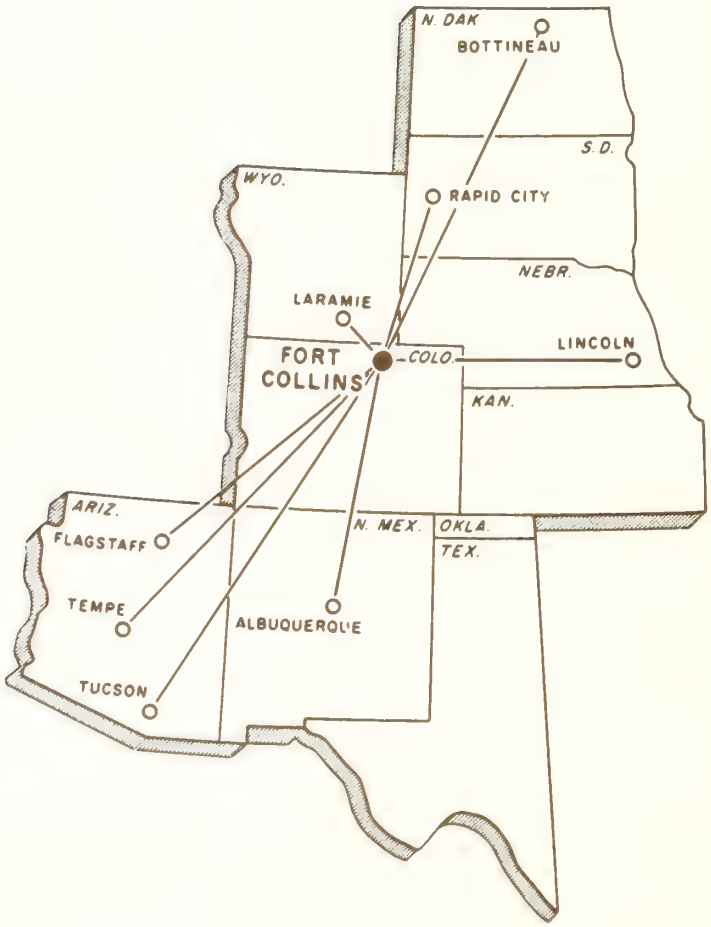
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INSECTS and MITES ASSOCIATED WITH DWARF MISTLETOES

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Abstract

Three main ecological relationships are recognized between arthropods and dwarf mistletoes (Arceuthobium spp.); the arthropods pollinate and feed on the dwarf mistletoes, and mistletoe infection may predispose trees or parts of trees to attack by insects, especially bark beetles (Scolytidae). Diptera, Hymenoptera, and Thysanoptera are the main pollinators. Larvae of Lepidoptera are the most important group of insects that feed on dwarf mistletoes, at times causing severe damage to external portions of plants. Several species of mites (Acarina) are common associates; their relationship with the host is unknown. Biological control may be possible through manipulating populations of insects that feed on or pollinate mistletoe.

Key words: Arceuthobium, biological control, pollination

ABOUT THE COVER:

Larvae of the thicket hairstreak butterfly, Mitoura spinetorum Hewitson, in typical feeding position on dwarf mistletoe shoots. Drawing by Anne Steely.

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September 1970

Insects and Mites Associated with Dwarf Mistletoes

by

Robert E. Stevens, Principal Entomologist

and

Frank G. Hawksworth, Principal Plant Pathologist

Rocky Mountain Forest and Range Experiment Station[1]

[1]Central headquarters maintained at Fort Collins, in cooperation with Colorado State University.

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Insects and Mites Associated with Dwarf Mistletoes

Robert E. Stevens and Frank G. Hawksworth

Dwarf mistletoes, Arceuthobium spp., parasitize conifers in North and Central America, Africa, and Eurasia, but most species are confined to the New World. In many parts of the western United States they are serious economic pests (Gill and Hawksworth 1961).

The literature on insects associated with other mistletoes is extensive (Schumacher 1918, Gill and Hawksworth 1961). Some of the more detailed accounts have been on Viscum album in Europe (Tubeuf 1923), Phoradendron flavescens in the United States (Tucker 1922), and Loranthus longiflorus in West Pakistan (Baloch and Mohyuddin 1969). The insects associated with the dwarf mistletoes have not been comparably reviewed, however. Hawksworth (1961) listed several species of insects found on Arceuthobium vaginatum subsp. cryptopodum,[4] a parasite of Pinus ponderosa Laws. in the southwestern United States, and several other insects have been reported on Arceuthobium. It is our purpose in this Paper to summarize all of this literature, and to present previously unpublished information on arthropods (insects and mites) associated with the dwarf mistletoes of the western United State and Mexico.[5]

[4]*The scientific names for Arceuthobium used in this paper are from "Biology and classification of the dwarf mistletoes," by Frank G. Hawksworth and Delbert Wiens, U. S. Dep. Agr., Agr. Handb. (in press). In the Arceuthobium campylopodum group, the specific names are usually the same as the form names used by Gill (1935). Exceptions are A. "occidentale"--a California species on Pinus sabiniana, P. radiata, and P. muricata; A. "californicum"--a species principally on Pinus lambertiana in California and southern Oregon; and A. "apachecum"--on Pinus strobiformis in southwestern United States and northern Mexico.*

The authors express their thanks to the many taxonomists who identified the insects.

Arthropod-Dwarf Mistletoe Relationships

Several kinds of insects and mites are associated with dwarf mistletoes, and these associations involve three main ecological relationships. Of these, two are direct relationships that involve insects as consumers and pollinators of dwarf mistletoe plants. A third, indirect, relationship concerns dwarf mistletoe infection predisposing trees or parts of trees to attack by insects. The relationship between dwarf mistletoes and insects has been somewhat of a "no-man's land" between forest entomology and forest pathology that has scarcely been investigated.

Most of the direct arthropod-dwarf mistletoe associations we report involve insects feeding on or pollinating dwarf mistletoe plants. However, in some instances—especially with mites—the relationship is unclear, and we do not know for certain what the arthropod is doing in or on the host plant.

Several of the arthropod species recorded in the literature are represented by a single or only a few collections. Again this is especially true for the mites, and probably reflects lack of attention rather than rarity of occurrence.

Pollination of Dwarf Mistletoes

Arthropods—especially insects—appear to play the major role in dwarf mistletoe pollination (Hawksworth 1961, Kuijt 1955, Weir 1915). Evidence for this centers on characters of insect pollinated plants demonstrated by Arceuthobium: spined pollen shed in clusters, relatively limited amount of pollen, nectar production, and odor emission by both male and female flowers, along with the presence of numerous insects in and on the flowers during the flowering period. Some wind pollination may occur, but probably only within a meter or so.

The most consistent association we have observed (table 1) is pollination of A. vaginatum subsp. cryptopodum by thrips. Thrips, including a species of Frankliniella and possibly others, occur essentially throughout the range of this mistletoe in the Southwest and in Colorado (Hawksworth 1961).

Table 1.--Insects known or suspected to pollinate dwarf mistletoes

Insect	Host	Tree	Locality	Reference[1]	Remarks
[illegible] Thrips					Thrips are small insects, generally less than 2 mm. long, with fringed wings. [illegible], the undescribed [illegible] (O'Neill, Kellie. 1970. Proc. Wash. Entomol. Soc. 72, in press), and [illegible] are common on [illegible] subsp. [illegible] in southwestern United States; together these are thought to be its primary pollinators (Hawksworth 1961). [illegible] is widespread throughout North America, it is found commonly in the flowers of a broad range of plants (Essig 1958). [illegible], an even more widespread thrips, occurs throughout Europe and North America; Essig (1958) indicates that it feeds on a wide variety of crops.
[illegible] (Anderson	[illegible] subsp.	[illegible]	Ariz.; N. Mex.	Hawksworth 1961	
[illegible]	do	do	do	do	
[illegible]	do	do	do	do	
[illegible] (Moulton)	[illegible]	[illegible]	Jacob Lake, Ariz.	(F. O'Neill)	
[illegible]	[illegible]	[illegible]	Bryce Canyon, Utah	do	
Unidentified [illegible]	[illegible]	[illegible]	Europe	Heinricher 1915	
Do	[illegible]	[illegible]	Pilgirs, Idaho	(Hawksworth)	
Do	do	do	Pringle Falls, Oreg.	do	
Do	do	do	Charleston Mts., Nev.	do	
Do	[illegible]	[illegible]	Bryce Canyon, Utah	do	
Do	do	do	San Francisco Peaks, Ariz.	do	
HYMENOPTERA					
Unidentified Hymenopterous insects	[illegible] spp.	not given	Northwestern U. S.	Weir 1915	
Formicidae--ants					
[illegible] Wheeler	[illegible]	[illegible]	Cody, Wyo.	(R. E. Gregg)	
[illegible] Emery	[illegible]	[illegible]	Larimer County, Colo.	do	
[illegible] Emery	do	do	do	do	
[illegible] (Say)	do	do	do	do	
Unidentified ants	do	do	British Columbia	Kuijt 1955	
Do	[illegible] subsp.	[illegible]	Ariz.; N. Mex.	Hawksworth 1961	
Apidae--Honey bees					
[illegible] Linnaeus	[illegible]	[illegible]	Calif.	Coleman 1921	
DIPTERA					
Sciaridae--Root gnats					
[illegible] sp.	[illegible]	[illegible]	Larimer County, Colo.	(A. Stone)	These small, fragile flies are common in and around dwarf mistletoe plants during the flowering period. An observation (June 1, 1962) on [illegible] in Larimer County, Colorado, showed 51 percent of the ♂ plants (n=88) being visited by [illegible], compared with 26 percent of the ♀ plants (n=31).
Unidentified flies	do	do	Uinta Mts., Utah	(D. Wiens)	

[1]References in parentheses are original; insects were identified by individual named.

During the flowering period, these normally dark insects appear yellow due to the masses of pollen transported on their bodies. Coleman (1921) records Arceuthobium campylopodum as a honey plant in California, so honeybees may also be involved in pollination of the species. W. V. Showalter (personal communication 1968) has observed bumblebees, other bees, and thrips apparently involved in pollination of A. campylopodum on ponderosa pine in California.

Our observations of Arceuthobium americanum in Colorado suggest that ants and flies are its primary pollinators. Early in the flowering period, small flies, particularly Bradysia sp. (Sciaridae), are most common, but toward the end of the flowering period the flies are succeeded by ants. Formica sanguinea subnuda Emery, Lasius niger neoniger Emery, and Tapinoma sessile (Say) have all been observed to frequent flowering plants and to transport pollen.

Some phytophagous insects (table 2) may be passively involved in pollination if their season of activity coincides with the flowering period of their host.

Cooperative University of Utah-Rocky Mountain Station studies on the pollinators of Arceuthobium americanum are currently being conducted by Dr. Delbert Wiens.

Insect Feeding on Dwarf Mistletoes

Several kinds of insects—especially larvae of Lepidoptera—feed on dwarf mistletoe plants (table 2). In some cases they are highly destructive. With a few exceptions the insects that feed on dwarf mistletoe have not been commonly collected, and little is known of their life histories and other characteristics. Three species of Lepidoptera, Filatima natalis (Heinrich), Dasypyga alternosquamella Heinrich, and Mitoura spinetorum (Hewitson), appear to be specific to Arceuthobium, and are broadly distributed throughout its range in western North America. Neoborella tumida Knight, a mirid bug, is also widely distributed in the West and appears to be restricted to Arceuthobium. The Lepidoptera larvae can all be highly destructive to individual plants, but the impact of their feeding on a broad scale has not been evaluated. N. tumida, while widely recognized as a dwarf mistletoe associate, has only this past season been conclusively found feeding on the host; the effect of its feeding has not been studied.

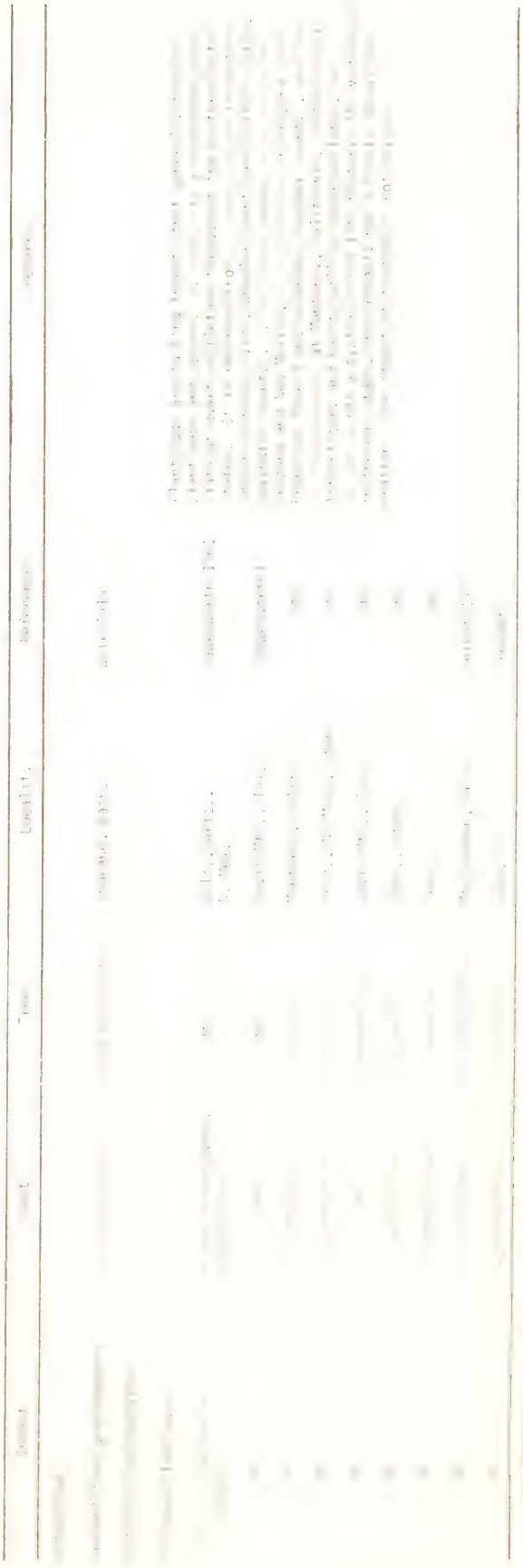

Table 2.--Insects known or reported to feed on dwarf mistletoe--continued

Insect	Host	Tree	Locality	Reference[1]	Remarks
[illegible] sp.	[illegible] subsp.	[illegible]	Puebla, Mexico	(Knight)	A specimen from [illegible] subsp. [illegible] from Popocatepetl--Ixtacciuatl National Park, State of Puebla, Mexico, was identified by Knight as [illegible] sp., possibly [illegible]. Knight also reports (personal communication, November 25, 1969) that another undescribed species may be associated with [illegible] in Arizona.
HEMIPTERA (HOMOPTERA)					
Diaspididae--Armored scales					
[illegible] Schrank	[illegible]	[illegible]	Europe	Schumacher 1918	
[illegible] Newst.	do	[illegible] spp.	Europe	Lindinger 1912	
[illegible] (Comstock)	[illegible]	[illegible]	Monterey County, Calif.	(H. L. McKenzie)	
[illegible] sp. (Undescribed)	[illegible] subsp.	[illegible]	Sinaloa, Mexico	(P. F. Wilkey)	
[illegible] Ferris	[illegible] subsp.	[illegible]	Durango, Mexico	do	Scale insects are rare on [illegible] in the U.S., but seem to be more common on material collected from Mexico. Many plants collected in 1963 had snoots that were almost 50 percent covered by [illegible]; however, there was no apparent damage.
Do	do	[illegible]	do	do	
Do	do	[illegible]	do	do	
Do	[illegible]	[illegible]	do	do	
Do	do	[illegible]	do	do	
Do	[illegible]	[illegible]	do	do	
Do	[illegible] subsp.	do	do	do	
Do	[illegible] subsp.	[illegible]	do	do	
Do	[illegible]	[illegible]	do	do	
Do	do	[illegible]	Oaxaca, Mexico	do	
[illegible] sp. (undescribed)	[illegible] subsp.	[illegible]	Veracruz, Mexico	do	
[illegible] T. & C.	[illegible]	[illegible]	Dominican Republic	do	
Unidentified black scale	[illegible] subsp.	[illegible]	Ariz., N. Mex.	Hawksworth 1961	

See footnote at end of table, p. 6.

Table 2.--Insects known or reported to feed on dwarf mistletoe--continued

Insect	Host	Tree	Locality	Reference	Remarks
[illegible]--Continued					Spittlebugs are also sucking insects, some of which are important plant pests. The common name refers to the habits of the nymphs (immature forms), that live and feed in masses of frothy spittle. Scriptchin and Long (1922) considered [illegible] to be the most conspicuous insect species found on [illegible]. It is widely distributed throughout the southwestern United States. Heavy populations can destroy entire dwarf mistletoe crops, but it is rarely abundant enough to cause such damage (Wadsworth 1961). While [illegible] commonly been cited as a species infesting dwarf mistletoe, it appears that only a single instance of authoritative identification has been made. The fact that [illegible]--now as the alder spittlebug--is well known from somewhat different kinds of hosts casts a question on the proper identity of the species actually involved with dwarf mistletoe. On the other hand, [illegible] lists [illegible] red cedar in addition to its more common broadleaf hosts. This implies a genetic host range and makes [illegible] a more likely [illegible].
[illegible]					
[illegible]	[illegible]	[illegible]	Manitou, Colo.	Hennigar 1961	Larvae of [illegible], and on undetermined conifers commonly, Douglas-fir, [illegible] in Southwestern United States. According to [illegible], the larvae not only cause [illegible] but also feed on the younger shoots and needles. Hennigar (1961) reared the [illegible] from Douglas-fir, [illegible], indicating that [illegible] of dwarf mistletoe are usually ingested. [illegible] found in the literature [illegible] this insect's [illegible].
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]					
[illegible]	[illegible]	[illegible]	[illegible], N. Mex.	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible], Calif.	[illegible]	

[illegible] Collected at ground level.

Table 2.--Insects known or reported to feed on dwarf mistletoe--continued

Insect	Host	Tree	Locality	Reference	Remarks
Lycaenidae--Hairstreaks					The hairstreaks, favorites of amateur lepidopterists, are a large group of small to moderate sized butterflies. [illegible], an especially attractive species, is widely distributed throughout montane western North America, from southern British Columbia to central Mexico. Shields (1965) gives a thorough review of its distribution and hosts, along with those of [illegible]. The larvae of [illegible] feed on all external parts of the dwarf mistletoe plant. The form of the larva, flag-like and with the segments irregularly folded and ridged, strongly resembles that of the host. This, coupled with the tendency of the larvae to take on the color of ingested food and a total lack of webbing, results in an excellent example of mimicry. The adult has been widely collected, and this has contributed much to the abundant distribution records compiled by Shields (1965). [illegible] feeds on several species of [illegible], while [illegible] has been recorded only on hemlock dwarf mistletoe, [illegible]. However, another host is likely for [illegible], as Shields (1965) records it from several locations in which [illegible] does not occur. Shields (1965) presents excellent colored photos of adults of both [illegible] species. [illegible] can cause severe damage to dwarf mistletoe plants. We have observed infections of [illegible] in Larimer County, Colorado, in which external portions of plants have been heavily damaged by larval feeding continuing over several seasons.
[illegible] (Hewitson)	[illegible] subsp.	[illegible]	Ariz., Colo.	Hawksworth 1961	
Do	[illegible]	do	Calif.	Comstock and Dammers	
Do	[illegible]	[illegible]	Mt. Diablo, Calif.	Tilden 1960	
Do	[illegible]	[illegible]	Ariz.	Barth 1950	
Do	do	[illegible]	Calif., Nev.	Shields 1965	
Do	[illegible]	[illegible]	Larimer County, Colo.	Remington 1968	
Do	[illegible]	[illegible]	Calif.	Shields 1965	
Do	[illegible]	[illegible]	Ariz.	do	
Do	[illegible]	[illegible]	Ariz.	do	
Do	[illegible]	[illegible]	Wash.	do	
Do	do	[illegible]	Wash.	do	
Do	[illegible]	[illegible]	Mexico	do	
[illegible] (Skinner)	[illegible]	[illegible]	Southern British Columbia, Canada; E. Oreg., E. Wash.	do	
Do	do	[illegible]	Sierra Nevada Mts., Calif.	do	
Lymantriidae--Tussock moths					This tussock moth was reported from the Targhee National Forest in southeastern Idaho in 1954 and 1955. It is found in the literature under the genera [illegible] and [illegible], [illegible] is known to be a feeder on a broad range of woody plants, but little is known of its habits on dwarf mistletoes. However, J. [illegible] Mielke (personal communication, 1959) reported nearly 100 percent of host shoots being destroyed in the southeastern Idaho outbreak, and indicated that it did not feed on the pine foliage.
[illegible] (L.)	[illegible]	[illegible]	Targhee National Forest, Idaho	(F. L. Todd)	
Pyralidae--Pyralid moths					This moth is another important destroyer of [illegible] subsp. [illegible] and [illegible], and is recorded from Colorado, Oregon, and California. Heinrich (1921) comments that "Larvae feed singly and externally and while normally very abundant are easily overlooked on account of their protective coloration. The color of the individual larvae varies in harmony with the color of the individual patches of mistletoe on which they feed." Heinrich also indicates a single annual generation, with the insects overwintering as pupae in the ground. It is probable that [illegible] is widely distributed throughout the range of ponderosa pine in the United States.
[illegible] Raganot	[illegible] subsp.	[illegible]	Colorado	Heinrich 1921	
Do	[illegible]	do	Ashland, Oreg. Hobergs, Lake Co., Calif.	(W. D. Duckworth)	
Tortricidae--Leaf roller moths					
Tortricid nr. [illegible]	[illegible] subsp.	do	Ariz., N. Mex.	Hawksworth 1961	
COLEOPTERA					
Curculionidae--Weevils					
Unidentified gray weevil	[illegible] subsp.	do	Ariz., N. Mex.	Hawksworth 1961	
Do	do	do	Larimer County, Colo.	(Hawksworth)	

[1]References in parentheses are original; insects were identified by individual named.

Mites

Several species of mites (table 3) have been collected from dwarf mistletoes. Brevipalpus porca Pritchard and Baker, a red tenuipalpid, is common throughout the southwestern United States. Typhlodromus arceuthobius Kennett is often associated with B. porca, and is probably a predator of it (Kennett 1963). Paraphytoptus arceuthobii Keifer is reported from staminate flowers (Keifer 1952). While B. porca and P. arceuthobii are members of phytophagous groups and could be expected to feed on the dwarf mistletoe plants, we have not seen this. B. porca, while not difficult to find, occurs in such low densities that visible damage would not be expected. The life history, habits, and ecological relationships of dwarf mistletoe-inhabiting mites remain to be learned.

Table 3.--Mites known to occur on dwarf mistletoes

Mite	Host	Tree	Locality	Reference[1]
MESOSTIGMATA				
Phytoseiidae				
Typhlodromus arceuthobius Kennett	*A. "occidentale"*	*Pinus sabiniana*	Mt. Diablo, Calif.	Kennett 1963
Do	do	do	Lake County, Calif.	Do
Do	do	do	Fiddletown, Amador County, Calif.	Do
Do	*A.*		Snow Lake, Plumas County, Calif.	Do
Do	do	do	Pinecrest, Tuolomne County, Calif.	Do
(Garman)	*A.*	*Picea mariana*	Stokes Bay, Ontario, Canada	Do
Do	do	do	Pine Tree Harbor, Ontario, Canada	Do
Do	do	do	Howdenvale, Bruce County, Ontario Canada	Do
Do	do	do	Outlet Park, Prince Edward County, Ontario, Canada	Do
Chant	*A. "occidentale"*	*Pinus sabiniana*	Lake County, Calif.	Do
Do	do	do	Fiddletown, Amador County, Calif.	Do
T. pusillus Kennett	*A. pusillum*	*Picea mariana*	Stokes Bay, Ontario, Canada	Do
Do	do	do	Howdenvale, Bruce County, Ontario, Canada	Do
Do	do	do	Troy, Cape Breton Island, Nova Scotia, Canada	Do
sp. nr. *roseilus*	do	do	Red Bay, Ontario, Canada	Do
TROMBIDIFORMES				
Eriophiidae				
Paraphytoptus arceuthobii Keifer		*Pinus jeffreyi*	Lake Tahoe, Calif.	Keifer 1952
Do	*A. "occidentale"*	*P. sabiniana*	Mt. Diablo, Calif.	Do
Tenuipalpidae				
Brevipalpus porca Pritchard & Baker	*A. vaginatum* subsp. *cryptopodum*	*P. ponderosa*	Flagstaff, Ariz.	Pritchard & Baker 1958
Do	do	do	Fort Valley, Ariz.	Do
Do	do	do	Mescalero Indian Reserv., N. Mex.	Do
Do	do	do	Bryce Canyon, Utah	Do
Do	*Arceuthobium* sp.	do	Calif.	Kennett 1963
Do	*A. douglasii*	*Pseudotsuga*	Bryce Canyon, Utah	Pritchard & Baker 1958
Do		*Pinus edulis*	Jacob Lake, Ariz.	Do
Unidentified mites		*P. ponderosa*	Charleston Mts., Nev.	(Hawksworth)

[1]References in parentheses are original; insects were identified by individual named.

Increased Tree Susceptibility to Insects Induced by Dwarf Mistletoe

The question is often asked "Since both dwarf mistletoes and bark beetles (Scolytidae) kill trees, is there a relationship between the activity of the two pests?" Although an indirect relationship does exist (the few pertinent reports are summarized in table 4), none of the published reports seems to indicate that these are important in pines. Dwarf

Table 4.--Reports of dwarf mistletoes predisposing trees to attack by bark beetles[1]

Tree and dwarf mistletoe	Insect	Locality	Reference[2]
Pseudotsuga menziesii			
Arceuthobium douglasii	*Dendroctonus pseudotsugae*	Pacific Northwest	Weir 1916
Do	do	Utah	Chick 1936[3]
Do	do	Southwest	(Hawksworth)
Pinus lambertiana			
Arceuthobium "californicum"	*Dendroctonus monticolae*	California	Struble 1965 Scharpf & Hawksworth 1968
Pinus ponderosa			
Arceuthobium vaginatum subsp. *[illegible]*	*[illegible]* sp.	Oregon	Miller & Keen 1960
Arceuthobium vaginatum subsp. *[illegible]*	*[illegible]* sp.	Southwest	Korstian & Long 1922 Hawksworth 1961
Pinus edulis			
Arceuthobium divaricatum	*Ips confusus*	Arizona	(Hawksworth)

[1]Dwarf mistletoe may also affect bark beetle brood production; this is apart from predisposition. In a recent study of *Dendroctonus ponderosae*, it was found that lodgepole pines moderately to heavily infected by *Arceuthobium americanum* were less suitable as brood trees because they have thinner bark than uninfected trees (Roe and Amman 1970).

[2]References in parentheses are original; insects were identified by individual named.

[3]Unpublished National Park Service report, on file at Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

mistletoes and bark beetles more often than not occur practically in the absence of each other. An important relationship may exist, however, between Douglas-fir dwarf mistletoe, A. douglasii, and the Douglas-fir beetle, Dendroctonus pseudotsugae Hopk., in interior Douglas-fir, Pseudotsuga menziesii var. glauca (Beissn.) Franco. Beetle outbreaks have been observed to develop in mistletoe-infected stands and spread out into uninfected timber. Further work is needed to clarify this relationship.

Miller and Keen (1960) discussed dwarf mistletoe-bark beetle relationships from the standpoint of the western pine beetle, Dendroctonus brevicomis Lec., and concluded that heavily infected ponderosa pines were three to five times more susceptible to beetle attack than uninfected trees. They further pointed out, however, that the mistletoe-infected trees are probably the older and more decadent trees in a stand, a factor in old-growth ponderosa pine that often contributes to beetle attack. Korstian and Long (1922) reported that, in an area near Flagstaff, Arizona, about 69 percent of the mortality in "black jack" ponderosa pines (trees under 125 to 150 years old) was attributable to mistletoe. About half of this mortality was due directly to mistletoe and half to the parasite in association with bark beetles. Struble (1965) indicated that dwarf mistletoe is common in old-growth sugar pine, Pinus lambertiana Dougl., attacked by the mountain pine beetle, Dendroctonus ponderosae Hopkins. The association appears to be similar to that reported by Miller and Keen (1960).

Other records of dwarf mistletoe-insect relationships include (1) the tendency of twig beetles, Pityopthorus and Pityogenes, to attack dwarf mistletoe-infected ponderosa pine branches in the Southwest (Hawksworth 1961), (2) the preference of an engraver beetle, Scolytus subscaber Leconte for branches of true firs, Abies spp., infected by dwarf mistletoe (Struble 1957), and (3) the attack by wood borers in dwarf mistletoe infections on the boles of western larch, Larix occidentalis Nutt., and ponderosa pine (Weir 1916).

Edmunds and Allen (1958) found no significant difference in population density of black pine leaf scales, Nuculaspis californicus (Coleman), infesting ponderosa pines near Spokane, Washington, with and without Arceuthobium campylopodum.

Possibilities for Dwarf Mistletoe Control through Manipulation of Insect Associates

The direct dwarf mistletoe-insect relationships (pollination and predation) suggest possibilities for biological control.

Two biological approaches might be considered. The first is the standard technique of introducing or augmenting populations of phytophagous insects. The potential for this seems theoretically favorable. A second, less conventional, approach would involve limiting pollination and subsequent mistletoe reproductive capacity by controlling or repelling the pollinators. In this way, dwarf mistletoes on seed trees might be rendered harmless so the trees could be safely left to regenerate new, mistletoe-free stands.

Either of these approaches could be combined with existing silvicultural control methods or new methods yet undeveloped to provide an integrated program.

A limited amount of effort has already been put into a search for predators. During the early 1960's, C. B. Huffaker and associates at the Division of Biological Control, University of California, Albany, made preliminary studies on arthropods affecting Arceuthobium. The description of new species of mites by Kennett (1963) is a result of this activity. Hawksworth has observed arthropods on various Arceuthobium species for a number of years, with biological control in mind. The possibilities do appear intriguing, but they can be realized only if economic and other benefits justify the work necessary to develop techniques.

Field Identification of Arthropods Found on Dwarf Mistletoes

The following preliminary field key is presented to enable nonspecialists to make tentative determinations of insects and mites found in or on dwarf mistletoes. We recognize that the key is not complete and generally does not permit identification to species. We expect that a more comprehensive key can be constructed as we get more information on some of the species involved.

Field Key to Insects and Mites Known to Occur on Dwarf Mistletoes[4]

1. Mites living in or on plants	*Typhlodromus* spp. *Brevipalpus porca* *Paraphytoptus arceuthobii*
2. Adult or nymphal insects living freely in or on plants	
A. With a single pair of wings, found mostly on flowers; flies	*Bradysia* sp., and other flies
AA. With two pairs of wings or wingless--B	
B. Wings fringed, small insects generally less than 2 mm. long, mostly on flowers; thrips	*Frankliniella occidentalis* *Frankliniella* sp. *Thrips tabaci*
BB. Wings not fringed, larger insects generally between 2 and 4 mm. long; true bugs	*Neoborella tumida*
BBB. Wingless, smaller but as BB	*N. tumida* nymphs
3. Insects living within a white, frothy mass; spittlebugs	*Clastoptera obtusa*
4. Hard shelled, sessile insects; scales	
A. On *A. oxycedri*, Europe	*Chionaspis striata* *Diaspis visci*
AA. On New World species	*Niveaspis* spp. *Hemiberlesia* spp.
5. Caterpillars feeding in or on shoots; moth larvae	*Pseudoparlatoria serrulata*
A. Larvae hairy; tussock moths	*Orgyia antiqua*
AA. Larvae not hairy- - - - - - - - - -B	
B. Larvae slug-shaped, segments in folds and ridges; hairstreaks	*Mitoura spinetorum* *M. johnsoni*
BB. Larvae not slug-shaped, segments smooth	*Dasypyga atermosquamella* *Filatima natalis* Tortricid nr. *peronea*

[4] *If identification to species is critical, specimens should be referred to specialists. Adult forms are needed for determination of species. Unidentified grasshoppers, thrips, scales, spittlebugs, geometrid moths, weevils, and ants, not included in the key, are also reported from dwarf mistletoes (see tables on individual species).*

Conclusions

Dwarf mistletoes harbor a considerable arthropod fauna, but we know little about the details of the ecological relationships involved. Insects do play a major role in pollination, and insect feeding can severely damage dwarf mistletoe plants, at least locally. In some instances, mistletoe appears to be related to increased tree susceptibility to insects.

There are many opportunities for further study of insect-dwarf mistletoe relationships. Practical as well as scientific benefits may be obtained, since dwarf mistletoe is an economic pest, and additional control techniques are needed. Manipulation of arthropod populations would provide another approach. Utilization of phytophagous insects is an obvious possibility. Another intriguing approach, since pollination by arthropods seems to be practically obligatory, is to limit the pollinators and thus reduce reproductive capacity of dwarf mistletoe. It may also be possible to combine biological control with other control methods to provide an effective integrated control program.

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Stevens, Robert E., and Hawksworth, Frank G.
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Three main ecological relationships are recognized between arthropods and dwarf mistletoes (Arceuthobium spp.); the arthropods pollinate and feed on the dwarf mistletoes, and mistletoe infection may predispose trees or parts of trees to attack by insects, especially bark beetles (Scolytidae). Diptera, Hymenoptera, and Thysanoptera are the main pollinators. Larvae of Lepidoptera are the most important group of insects that feed on dwarf mistletoes, at times causing severe damage to external portions of plants. Several species of mites (Acarina) are common associates; their relationship with the host is unknown. Biological control may be possible through manipulating populations of insects that feed on or pollinate mistletoe.

Key words: Arceuthobium, biological control, pollination

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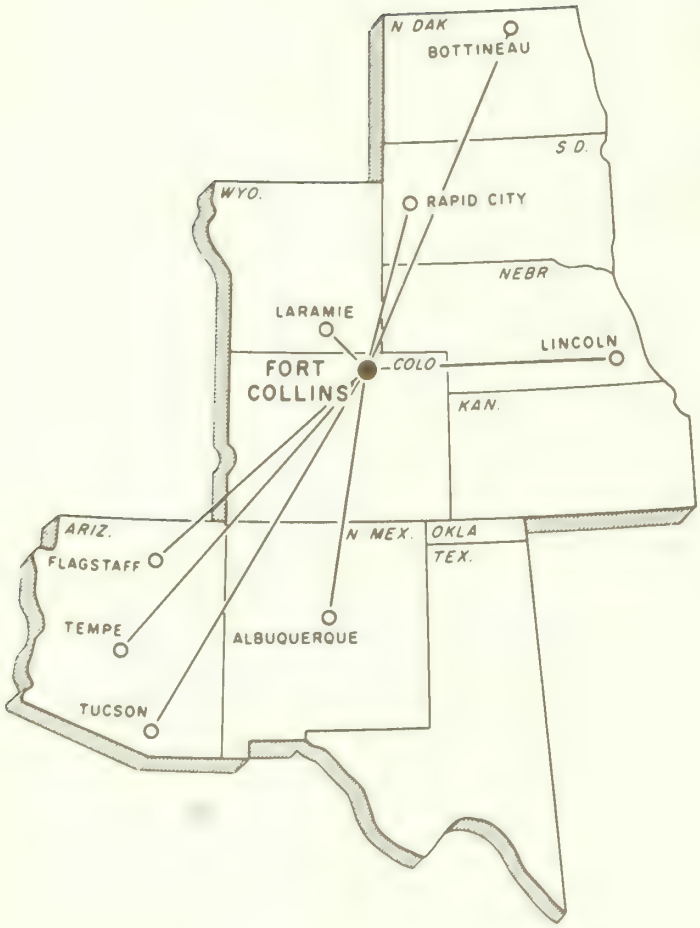
Three main ecological relationships are recognized between arthropods and dwarf mistletoes (Arceuthobium spp.); the arthropods pollinate and feed on the dwarf mistletoes, and mistletoe infection may predispose trees or parts of trees to attack by insects, especially bark beetles (Scolytidae). Diptera, Hymenoptera, and Thysanoptera are the main pollinators. Larvae of Lepidoptera are the most important group of insects that feed on dwarf mistletoes, at times causing severe damage to external portions of plants. Several species of mites (Acarina) are common associates; their relationship with the host is unknown. Biological control may be possible through manipulating populations of insects that feed on or pollinate mistletoe.

Key words: Arceuthobium, biological control, pollination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USDA Forest Service
Research Paper RM-60

September 1970

Runoff and Erosion Control by Seeded and Native Vegetation on a Forest Burn: Black Hills, South Dakota

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Howard K. Orr

Rocky Mountain Forest and Range Experiment Station
Forest Service U. S. Department of Agriculture
Fort Collins, Colorado

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ABSTRACT

Growth of seeded species in combination with reestablishment of native vegetation reduced overland runoff and soil erosion to tolerable levels within one to four growing seasons. Gross rainfall was a poor indicator of runoff and soil erosion from small plots. Trends were best defined by declining rates of runoff and sediment production per unit of excess rainfall. Sixty percent ground-cover density (live vegetation plus litter) is postulated as the minimum necessary for soil stabilization. This cover density almost certainly could not have been reached within the 4-year study period without seeding. Seeded grasses—timothy and Kentucky bluegrass on coarse-textured soil and timothy and smooth brome on fine-textured soil—were especially important because of their dispersion and abundance, and persistence of litter production.

Key words: Soil stabilization, ground-cover plants, runoff, forest fire control

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Runoff and Erosion Control by Seeded and Native Vegetation on a Forest Burn: Black Hills, South Dakota

by

Howard K. Orr, Hydrologist

Rocky Mountain Forest and Range Experiment Station[1]

[1]Central headquarters maintained in cooperation with Colorado State University; research reported here was conducted in cooperation with South Dakota School of Mines and Technology at Rapid City.

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Runoff and Erosion Control by Seeded and Native Vegetation on a Forest Burn: Black Hills, South Dakota

Howard K. Orr

Introduction

Accelerated runoff and soil erosion are natural aftereffects of many intense forest burns. Nature alone will eventually restore a burned area to a condition of stability and equilibrium, but perhaps not for a long time. Consequently, artificial measures are planned to counteract natural destructive forces, and thus speed up the soil stabilization process.

Rehabilitation often consists of a combination of overlapping measures. With more complete understanding of basic runoff-erosion relationships and trends, treatment overlap and overall cost of rehabilitation may be reduced.

The 4,500-acre Deadwood fire of September 1959 provided an opportunity for study and evaluation of specific aspects of applied rehabilitation measures. Precipitation variables and ground-cover development were analyzed to determine their relationship to trends in surface runoff and erosion.

The Burn

Site Characteristics

The burn area (fig. 1) is in the highest precipitation zone of the Black Hills. Annual precipitation averages nearly 28 inches, and ranged from 18.0 to 48.4 inches over a 34-year period of record at Deadwood. Most abundant precipitation is produced by frontal-type storms during May and June. Convective thunderstorms and high-intensity rainfall are most common in July, and gradually diminish through August and September. Snowfall accounts for practically all precipitation from October through April. Heavy, wet spring snows are fairly common, and a number of rain-on-snow events have caused widespread flooding over the Black Hills area.

Both crystalline and sedimentary rock formations account for wide soil variations in the burn area.

Second-growth ponderosa pine[2/] 80 to 90 years old dominated the area. Stands were typically dense post-pole size trees with small intermingled patches of sawtimber. Forest floor vegetation was sparse, a common condition in the typically dense second-growth pine stands of the Black Hills. Little other vegetation was present except for sparse grass cover and some common juniper on south slopes and along the crests of some rocky ridges, and scattered bearberry and creeping mahonia.

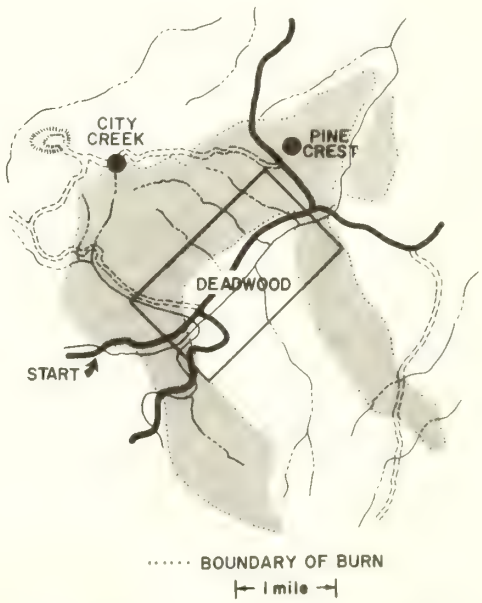

Figure 1.--Map of the September 1959 Deadwood Burn and surrounding area (Black Hills, South Dakota).

The Fire

The Deadwood Fire started on September 8, 1959, and within 24 hours burned over an area of about 4,500 acres. Fire danger was extreme throughout the period. Virtually all trees were killed and all forest floor organic matter was consumed over extensive areas. In early stages, when hottest, the fire moved across a series of steep side-by-side watersheds that drain almost directly south into the town of Deadwood (fig. 1), which itself was threatened by fire that burned into the outskirts.

[2] *Common and botanical names of plants mentioned are listed on page 12.*

Rehabilitation Measures

Extensive rehabilitation measures included artificial seeding of adaptable grasses and legumes on 4,011 acres. The entire treatment was designed to reduce by 68 percent the estimated potential flood damage from a 10-year-frequency storm in the first year after the fire.

Because of the threat of flooding during the normally heavy precipitation period of spring and early summer, primary treatment started while snow remained on the ground, and concluded with the April 4-8 helicopter seeding (on snow) of 11 pounds per acre of a grass-legume mixture:

Species	Pounds/acre
Timothy	3
Smooth brome	3
Kentucky bluegrass	2
Yellow sweetclover	2
Hairy vetch	1
Total	11

The Study Area

Two distinctly different areas were selected for detailed study. One was at the head of City Creek (fig. 1) on stony-loam soil developed from fine-grained Tertiary igneous intrusives or Precambrian quartz-mica or mica schists. Elevation was 5,400 feet (MSL). The other was at Pine Crest, several miles to the east, at elevation 4,900 feet in an area of finer textured loam to clay soil derived from massive light-colored Pahasapa limestone of Paleozoic origin.

At each site, eight 1-milacre runoff plots were installed in July and early August 1960; four on a south- to southwest-facing slope, and four on the north- to northeast-facing slope just over the adjacent ridge. By July some seeded species were becoming well established, and native cover was starting to reappear.

Two plots in each group of four were intentionally selected at sites on which total ground cover was relatively sparse, and two where cover was already relatively dense. Obvious atypical rock concentrations or other soil surface conditions were carefully avoided. Initial ground-cover densities (live vegetation plus litter) ranged from about 10 to 80 percent at City Creek and 10 to 33 percent at Pine Crest. Plots with the highest initial ground-cover densities generally had the highest percentages of seeded plant species.

The plots were 4 by 10.9 feet, with the long axis parallel to the slope (fig. 2). Sheet-metal frames were driven 3 to 4 inches into the soil. A collection trough along the lower boundary of each plot funneled runoff into a collection tank. Runoff plus sediment was measured by weighing. Sediment was then dried and weighed.

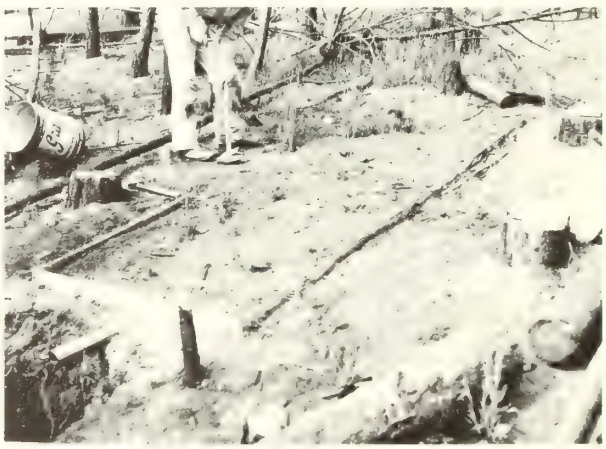

Figure 2.--Runoff plot installation. Plot frames were driven 3 to 4 inches into the ground in sections, then spliced together watertight.

Vegetation on all plots was surveyed and photographed during the period of maximum plant development in July or August each year of study. Six 1- by 2-foot subplots were examined on each 1-milacre runoff plot. During the same periods, surveys were also made on 2-square-foot plots at 50- to 100-foot intervals on two cross-country transects in the vicinity of each of the two major study sites. Number of plots per transect ranged from 10 to 30. Percentage live vegetation, litter, exposed rock, and bare soil on each runoff subplot and each transect plot were estimated visually. All identifiable plant species were listed. The three dominant species were then ranked 3, 2, or 1 in descending order of abundance and proportion of ground cover. The numerical ranking of the three most dominant species on each observation plot made it possible to define general ground-cover density and composition trends.

Primary climatic records were obtained with one centrally located standard precipitation gage and one recording gage at each of the two sites. Precipitation records were collected at monthly intervals during the winter months (October-March). All

plots were checked at the same time, and any snowmelt runoff was measured. More frequent observations were started prior to the general thaw, usually in March, and both precipitation and runoff observations were continued at 1-week intervals through September. More frequent measurements were taken in case of major storms. Plot runoff observations were started in August 1960 and continued through the growing season of 1963.

The first two postburn years were unusually dry, and the third and fourth years were unusually wet (table 1). Calendar year 1961 ranked lowest of 34 years of record at Deadwood. Precipitation then rose to far above average in 1962. Individual storms were larger and more intense than in the other years. In May alone 13.7 inches fell at City Creek and 11.6 inches at Pine Crest. The calendar year ranked fourth wettest of the 34 years of record. Calendar year 1963 continued above average, especially the winter months, and ranked fifth wettest of record.

Table 1.--Seasonal precipitation by water years at the two study sites

Water year	City Creek		Pine Crest	
	Oct.-Apr.	May-Sept.	Oct.-Apr.	May-Sept.
	Inches			
1960-61	8.48	9.64	([1])	8.16
1961-62	12.44	27.61	7.32	25.70
1962-63	19.10	14.62	12.28	13.06
1963-64	11.48	([2])	7.50	([2])

[1]Prior to installation of gages.
[2]Records discontinued.

Study Results

Ground-cover Density and Composition

Despite below-average precipitation through the winter and spring months (1959-60), some of the seeded species germinated and became established quickly, and some native species germinated or sprouted and started to regrow. Ground cover was already significant though highly variable when plots were installed in July and early August 1960. Precipitation had been just over 1 inch in May (less than 25 percent of average), about 3.75 inches in June (about 85 percent of average), and 1.6 inches (about 50 percent of average) in July.

"Patchiness" of ground cover when plots were selected and installed was striking; a broad range of immediate runoff and erosion potentials was evident at both sites (figs. 3, 4). The primary composition trends are illustrated in figure 5.

Highlights of ground-cover density and composition trends at City Creek during the 4 years of study were:

1. Quick establishment and persistent dominance of timothy.
2. Slowly increasing prominence of smooth brome (seeded), snowbrush ceanothus, and creeping mahonia (natives).
3. Sharp increase of Kentucky bluegrass in 1962 in apparent response to the far-above-average precipitation.
4. Initial prominence of American dragonhead, Carolina geranium (both native annuals), and yellow sweetclover (seeded biennial), and their almost complete disappearance by the second or third growing season.

Ground-cover density and composition characteristics and trends were somewhat different at Pine Crest. Main characteristics there were:

1. Initial prominence of seeded sweetclover and its apparent demise.
2. Codominance of seeded timothy.
3. The slow persistent increase and final prominence of smooth brome (seeded) and creeping mahonia (native).
4. Initial prominence of Carolina geranium (native annual) and its almost complete disappearance in the second growing season.

The major differences in cover density and composition between the two sites appear to have been due primarily to basic soil differences. Ground cover developed more quickly and to higher initial density on the coarse-textured soil at City Creek than on the finer textured, limestone-derived soil at Pine Crest. Pine Crest caught up quickly, however. By the end of the 1962 growing season, both sparse and dense plots at Pine Crest had more live cover than at City Creek. Some of the dense plots at City Creek appear to have reached their maximum production of live vegetation as early as 1960, and all plots by the end of the growing season in 1962. This contention is supported by the fact that there was an appreciable drop in amount of live cover on seven of eight plots at City Creek from 1962 to 1963, despite near- or slightly above-average precipitation, while live cover remained static or further increased at Pine Crest. Cover developed more rapidly at City Creek, but the Pine Crest site appeared to have the higher production potential.

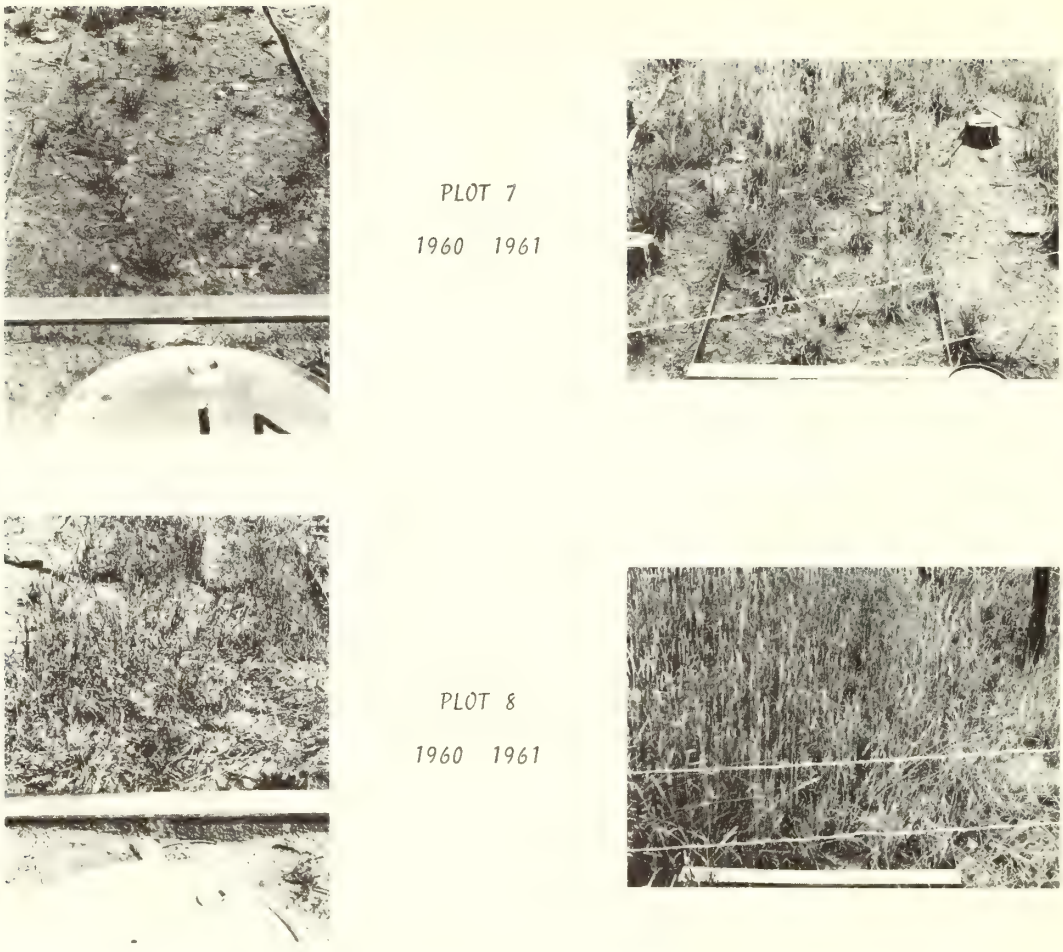

Figure 3.--Runoff plots 7 and 8 on a southwest-facing slope at City Creek in August 1960 and August 1961. A large difference in runoff and erosion potential between plots and between years is visible.

All of the seeded species except hairy vetch were important cover components at one or both of the sites at some time during the study period.

Timothy, which was important at both sites throughout the study, consistently maintained a higher degree of dominance at City Creek than at Pine Crest. Kentucky bluegrass became an important cover component at City Creek in 1962 but never was important at Pine Crest. Smooth brome increased slowly but surely and became an important species at both sites by the fourth growing season. Growth was generally more vigorous and of higher ranking at Pine Crest, however, where it was co-dominant with timothy and creeping mahonia in the general area at the end of the study.

Yellow sweetclover showed markedly different behavior at the two sites. New seedlings were abundant at both sites in 1960. At City Creek, most of the second-year growth was spindly and weak; at Pine Crest, it was tall and vigorous. The third season, practically none could be found at City Creek. First-year seedlings were abundant at Pine Crest in 1962 and again in 1963, but few developed into mature second-year plants.

From 15 to 20 more species were present each year at both sites than are shown in figure 5. Pine Crest generally had the greater variety of native species, and they made up a larger percentage of total cover than at City Creek. The more important of these easily observed but less frequently encountered species, mostly shrubs, were:

City Creek	Pine Crest
Spirea	Serviceberry
American red raspberry	Clematis
Spreading dogbane	Spreading dogbane
Common chokecherry	Common chokecherry
Rose species	Aster species

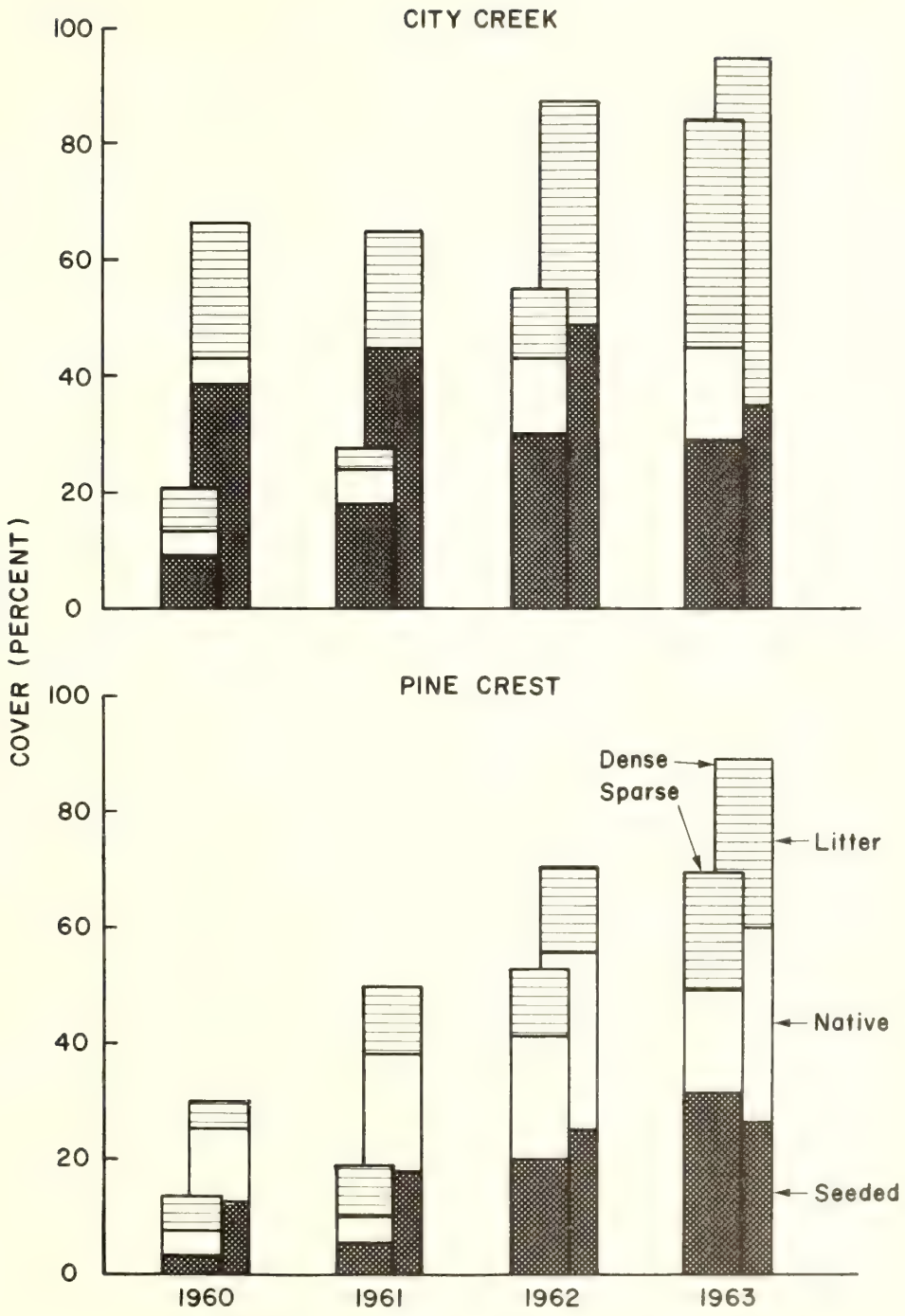

Figure 4.--Live vegetation (native and seeded) and litter-density trends on City Creek and Pine Crest runoff plots. Each bar represents the yearly average of four plots.

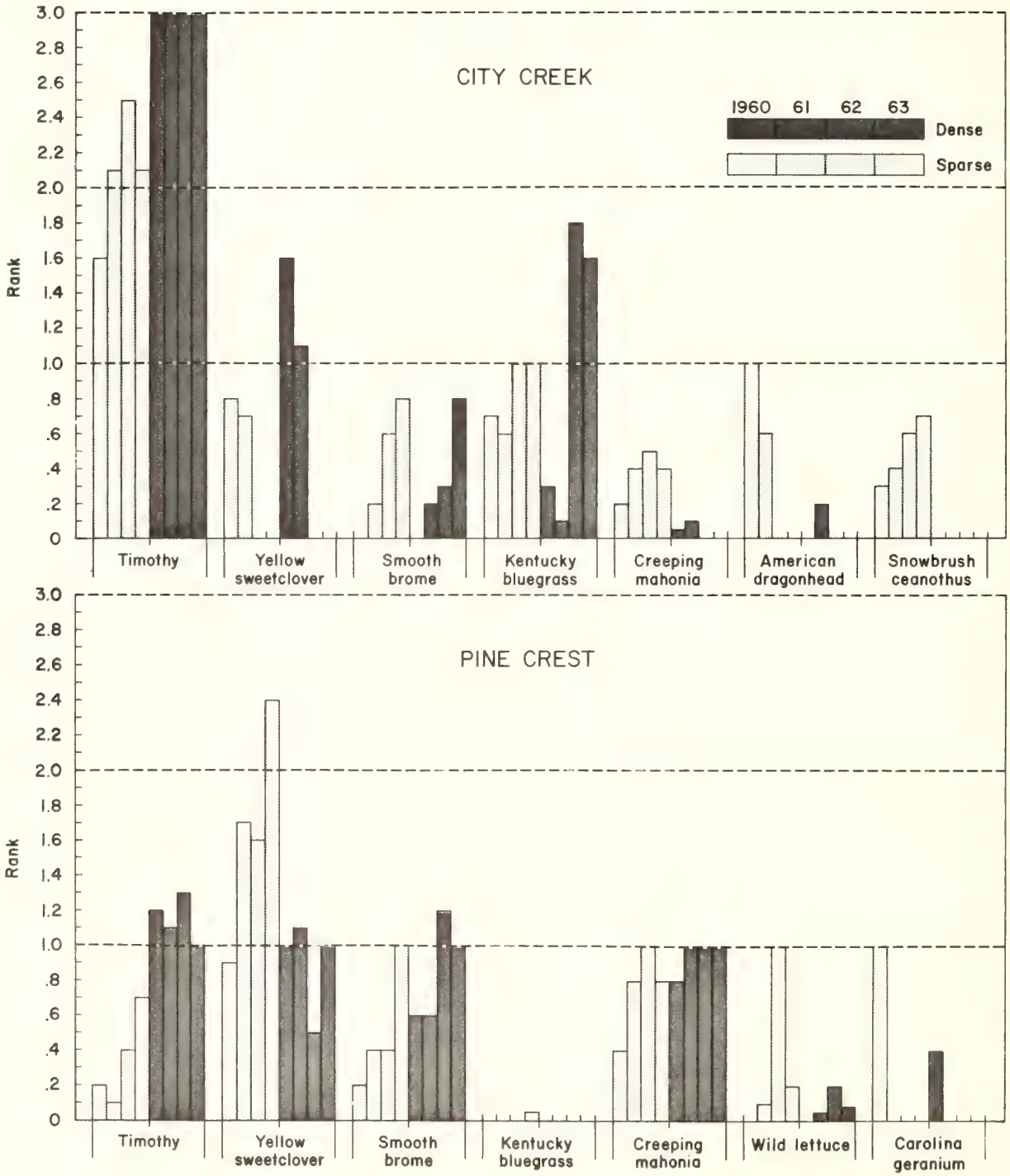

Figure 5.--Primary ground cover composition trends at City Creek and at Pine Crest in terms of cover rank, 1960-63.

Summer Runoff and Sediment

Between August 5 (date runoff-plot installations were completed) and September 30, 1960, a total of 3.91 inches of precipitation fell at City Creek and 3.93 inches at Pine Crest. Runoff was significant on only two occasions (table 2)—August 5-8 when 1.52 inches of precipitation fell at City Creek and 1.33 inches at Pine Crest, and August 19 when 1.15 inches was recorded at City Creek and 1.60 inches at Pine Crest. From limited records at City Creek, rainfall intensities apparently were no greater and probably were less than for comparable amounts of rainfall later in the study. More sediment came off all the plots in these two storm periods than in all of the three following summer seasons combined. Although some of this sediment may have resulted from installation disturbance, the inverse relationship of both runoff and sediment with ground cover is obvious.

Table 2.--Total summer storm runoff and sediment between August 5 and September 30, 1960

Site and plot cover class	Runoff[1]	Sediment[1]	Ground cover[2]
	Inches	Pounds/acre	Percent
CITY CREEK:			
Dense	0.50	757	67
Sparse	.89	4,472	20
PINE CREST:			
Dense	.70	2,883	30
Sparse	1.44	13,246	13

[1]Average of four plots.
[2]Live vegetation plus litter.

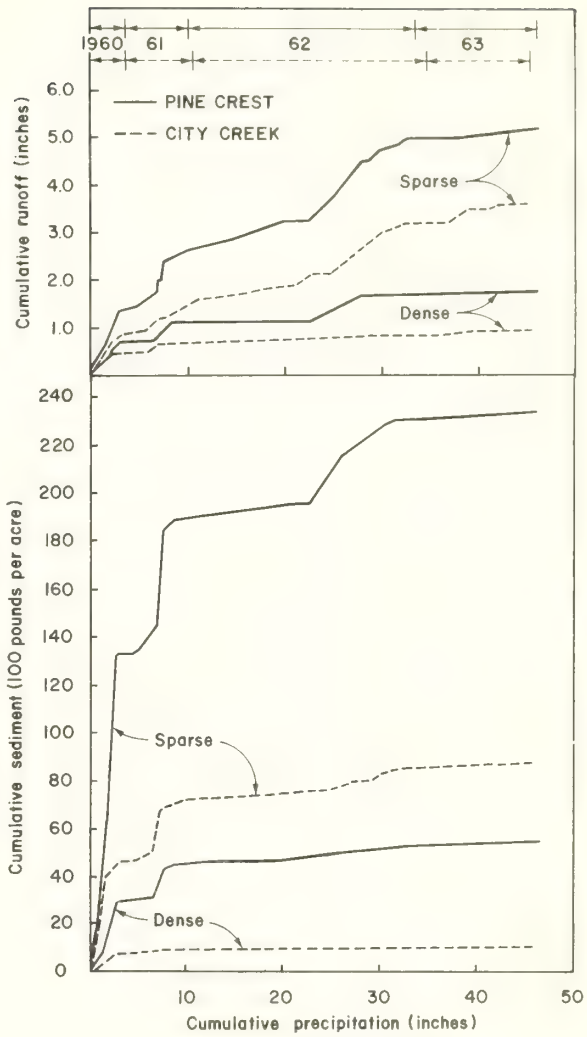

Figure 6.--Mass plot of summer storm runoff against precipitation and of sediment production in relation to gross precipitation, 1960-63 inclusive, at the two study sites.

Rates of runoff and sediment accumulation per unit of cumulative gross precipitation declined sharply in succeeding years (fig. 6). The apparent trends continued in the same order as initial 1960 differences in ground cover (live vegetation plus litter) between sparse- and dense-cover plots at the two sites and between sites. In these comparisons, north- and south-slope plots were combined since there were no clearly apparent or consistent effects of aspect, slope, or soil differences.

Several midseason accelerations of runoff and sediment accumulation cannot be attributed to decline in ground cover, since they occurred when vegetation was near its maximum seasonal development. They can more obviously be explained by seasonal variation in precipitation characteristics.

Regression techniques were used in attempting to account for these midseason anomalies and to quantitatively test the runoff and sediment production trends. Regressions of runoff and sediment production on gross precipitation were calculated for individual years. The rationale for computing direct regression of sediment on precipitation rather than on runoff is drawn from several well-known sources (Ellison 1945, Musgrave 1947, USDA 1961), who define soil detachment and sheet erosion in terms of the kinetic energy of rainfall and site characteristics, including soil erodibility and ground

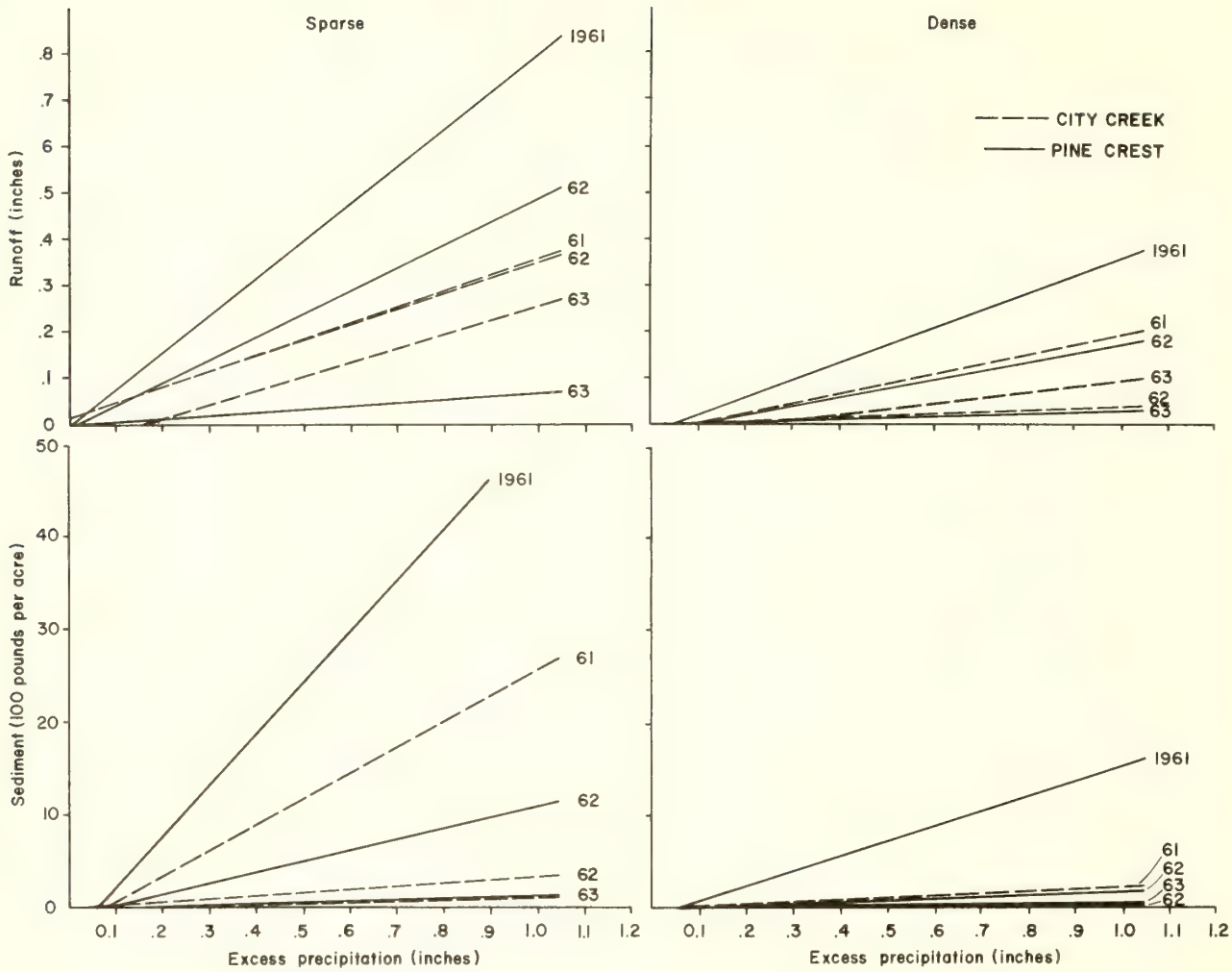

Figure 7.--Regression of summer storm runoff and sediment production on 0.03-inch-per-minute precipitation excess for 1961, 1962, and 1963.

cover. Unfortunately, the year 1960 could not be included in these analyses because of incomplete precipitation records. Of the remaining 3 years, gross precipitation alone accounted for a significant portion of runoff and sediment variance only in the exceptionally wet year 1962 ($P. \leq 0.05$). Thus, gross precipitation was a relatively poor indicator of runoff and sediment production.

Precipitation intensity was then introduced into the analysis in the form of an excess rainfall factor, which in effect was an indirect expression of infiltration rates. The factor was computed as total rainfall during a measurement interval that fell at a rate in excess of 0.03 inch per 5 minutes (0.36 inch per hour). Both higher and lower base rates were tested, but the 0.03-inch factor accounted for the most consistent proportion of runoff and sediment variance throughout the period of record.

The excess rainfall-runoff relationships (fig. 7, table 3) were all significant to highly significant ($P \leq 0.05$) in all 3 years on both classes of plots at both sites. The excess rainfall-sediment production relationships (fig. 7, table 3) were also all significant to highly significant except for City Creek dense-cover plots in 1963, when sediment production was too low to define a statistically significant trend. Cumulative plottings of runoff and sediment against excess precipitation were obviously less erratic than the plots against gross precipitation (fig. 6).

The year-to-year trends were tested by comparing regressions of runoff and sediment production on the excess rainfall factor by individual years. This is a more exact method than use of covariance to test significance of changes in slope of the overall run-

Table 3.--Regression of summer storm runoff (Y = inches) and sediment production (Y = pounds per acre) on 0.03 inch per 5 minutes excess rainfall (X), and estimates for the overall average 0.24 inch of excess rainfall per observation interval

Site and Year	Coefficient of determination		Regression equation constants for Y = a + bX				Estimates[1]	
			Dense		Sparse			
	Dense	Sparse	(a)	(b)	(a)	(b)	Dense	Sparse
RUNOFF (Inches)								
CITY CREEK:								
1961	0.647**	0.425*	-0.015	0.2054	0.011	0.3419	0.034	0.093
1962	.546**	.703**	- .001	.0363	.013	.3367	.008	.094
1963	.956**	.965**	- .028	.1204	- .050	.3070	.001	.024
PINE CREST:								
1961	.791**	.898**	- .016	.3722	- .006	.8017	.073	.186
1962	.819**	.892**	- .020	.1901	- .011	.4934	.026	.108
1963	.858**	.821**	- .002	.0308	- .000	.0675	.005	.015
SEDIMENT PRODUCTION (Pounds/acre)								
CITY CREEK:								
1961	.649**	.749**	- 15.8	235.9	-221.9	2770.4	41.0	443
1962	.704**	.866**	- 0.4	8.1	- 2.3	327.1	1.5	76
1963	.438NS	.536*	- 2.2	17.4	4.6	84.1	2.0	25
PINE CREST:								
1961	.832**	.872**	- 92.0	1615.9	-291.6	5465.8	296.0	1020
1962	.843**	.935**	- 8.9	169.1	-103.3	1205.2	32.0	186
1963	.790**	.788**	.2	47.5	- 1.5	115.1	12.0	21

[1] Separation lines indicate approximate points in time after which it is postulated that runoff and sediment production rates were within tolerable limits.
* Significant at .05 level.
** Significant at .01 level.
NS Not significant at .05 level.

off and sediment accumulation curves (Dawdy and Matalas 1964, p.8-76). All comparisons were based on assumption of linear relationships, since tests of several of the more questionable cases did not clearly indicate curvilinearity. Where variances were significantly different, approximate tests were made with adjusted degrees of freedom.

Three broad generalizations are at first apparent in figure 7 and in table 3:

1. There was a significant drop in runoff and sediment production per unit of excess rainfall from one year to the next on both sparse- and dense-cover plots at both sites.
2. There was significantly less runoff and sediment production per unit of excess rainfall from dense- than sparse-cover plots at both sites in all 3 years.
3. There was significantly less runoff and sediment production from City Creek sparse- and dense-cover plots than from Pine Crest sparse- and dense-cover plots in all 3 years.

These generalizations indicate decreasing runoff and sediment production as ground-cover density increased with time. However, there are several noteworthy exceptions to these general interpretations.

The City Creek sparse-cover plots did not show significant change in the excess-rainfall/runoff-production relationship from 1961 to 1962 despite a sharp increase in average ground-cover density. The regression lines in figure 7 coincide almost perfectly, and the regression equations in table 3 are almost identical. There also was no significant change in runoff production per increment of excess rainfall from 1962 to 1963. The slope of the regression remained almost the same. However, a significantly greater amount of excess rainfall was necessary to start runoff production in 1963 than in 1961 or 1962. Hence, a given amount of excess rainfall would have been expected to produce significantly less runoff in 1963 than in 1961 or 1962.

The 1961 and 1962 regressions for City Creek sparse-cover plots indicate slight amounts of runoff when there was no rainfall excess. Although no overall slope effects were readily apparent, slope steepness may have been a factor in this rather atypical runoff behavior. Average slope gradient was 8 percent greater than City Creek dense-cover plots and 12 percent greater than the Pine Crest sparse-cover plots.

A second exception involves runoff production rates on City Creek dense-cover plots. They show a significant decline from 1961 to 1962 as average total ground cover increased from about 65 to 87 percent, but the trend reversed in 1963. Runoff increased slightly despite a further increase in total ground cover. The only apparent explanation is the substantial drop in live cover from 1962 to 1963; the increase in total cover was due primarily to litter carryover from grass production in 1962.

A third exception involves comparison of runoff production rates at the two sites. City Creek dense- and sparse-cover plots had more total ground cover and produced less runoff per increment of excess precipitation than Pine Crest dense- and sparse-cover plots in both 1961 and 1962. In 1963 the situation reversed. Pine Crest plots yielded significantly less runoff per increment of excess precipitation than City Creek. Total ground cover continued slightly greater at City Creek than at Pine Crest, but for the first time Pine Crest had more live cover than City Creek.

The initial generalizations are more consistent for sediment comparisons than for runoff. There are no noteworthy exceptions, which in itself is significant. For example, runoff relationships were almost identical on City Creek sparse-cover plots in 1961 and 1962, yet there was a significant drop in sediment production per increment of excess precipitation. Hence, there was a significant drop in sediment production per unit of runoff. In fact, the decline in sediment production rates was of greater relative magnitude than for runoff throughout the study period, which indicates a steady reduction of sediment yield per unit of runoff.

Winter Runoff

The test plots also yielded significant winter runoff, with pronounced differences between the two sites. The City Creek plots consistently yielded from two to six times more snowmelt runoff than rainfall runoff. Pine Crest plots, on the other hand, produced only from about one-fourth as much to about the same amount of snowmelt runoff as rainfall runoff, and only about one-third to one-eighth as much as City Creek. Snowmelt runoff did not produce significant amounts of sediment.

The difference in snowmelt runoff between the two sites was primarily due to differences in amount and distribution of snow, and in the nature of soil freezing. The City Creek site characteristically received 1.5 to 1.7 times more winter precipitation than Pine Crest. At City Creek snow accumulated and remained on the ground all winter. Little snow accumulated at the more exposed and windswept Pine Crest site, and what did accumulate usually melted between storms.

Concrete frost characteristically formed at City Creek and made the soil practically impervious to water. On a number of occasions, sometimes in midwinter, a 1- to 2-inch-thick semifluid layer of free water and soil was noted on top of still solidly frozen soil. No such condition was ever noted at Pine Crest; frost crystals could be easily seen in the top 3 to 4 inches of soil, but the soil could still be turned easily with a shovel.

Winter runoff may occur in any of the winter months in the Black Hills. South and southwest slopes yield runoff more evenly distributed through the winter months than do the north-facing slopes. The general thaw, which usually occurs in late March or early April, produces the bulk of snowmelt runoff from north slopes.

At no time during the study was there consistent evidence of a relationship between snowmelt runoff and ground cover. The amount and time distribution of snowmelt runoff was controlled primarily by amount and aerial distribution of snow and by aspect.

Discussion

Summer storm runoff was under control and the soil had been stabilized by the end of the 4 years of study—considerably sooner on some sites.

From a strictly statistical standpoint, the plots in general yielded significant though declining amounts of runoff and sediment per increment of excess precipitation to the end of the study. Consider, however, the production of runoff and sediment in relation to ground-cover development trends.

Estimated runoff and sediment for the 0.24-inch mean of excess rainfall per observation interval for 3 summers of record at both sites are shown in

table 3. A plot of these values against average total ground cover showed a progressive deceleration of runoff production as total ground cover increased to about 60 percent. With further increase in ground cover, runoff declined at a slow, steady rate of only about 0.01 inch per 10 percent increase in ground cover. Sediment production showed an even sharper deceleration with increasing ground-cover density, and it too leveled out to a low, constant rate at about 60 percent total ground cover.

In a 1951 study of watershed protection requirements, Packer (1951) showed a similar type of relationship, with runoff and sediment production leveling off to insignificant rates at about 70 percent total ground cover. His study involved infiltrometer tests on wheatgrass and cheatgrass range on coarse-textured granitic soils in south-central Idaho. A similar infiltrometer study on finer textured soils in a subalpine range in central Utah[3/] showed continuing deceleration of runoff all the way to 100 percent ground cover, but a deceleration of sediment production to a slow, constant rate at about 65 percent total ground cover. In both these studies, the approximate ground-cover densities at which sedimentation rates became constant were considered the safe minimum for site stability. If the same criteria are applied to the present study, the City Creek dense-cover plots reached a point of minimum stability by the end of the first year after the burn, the Pine Crest dense plots by the end of the summer in 1962, and the sparse-cover plots at both sites by the end of the summer in 1963 —all within 3 to 4 years after the fire.

If the transects are considered more representative of the entire burn, the 60 percent ground cover criteria indicates that generally east-facing slopes in the City Creek area were stabilized by the end of 1961, generally west-facing slopes not until about midseason 1963, and the general Pine Crest area by midsummer 1962.

Seeded species dominated the cover at both sites throughout the study (fig. 5). Seeded species approached or exceeded 50 percent of live cover and reached nearly 100 percent. Actual cover provided by seeded species also increased steadily except for dense-cover plots in 1963. These plots had apparently already reached their herbaceous production potential, and live cover declined in apparent response to a drop in rainfall from the unusually wet year 1962.

Sweetclover was a relatively important cover component at both sites at the start, but quickly gave way to the grasses—timothy and Kentucky bluegrass at City Creek, and timothy and smooth brome at Pine Crest. These seeded grasses played key roles in the stabilization process in two special respects. In growth characteristics they provided a more evenly dispersed cover than native species—an important requirement in site stability[3/] (Packer 1951)— and they supplied the bulk of the steady accumulation of litter cover.

In the early stages of vegetation development, when density was low, the cover provided by seeded species must have supplemented cover provided by native species, since total cover was generally so sparse as to rule out the likelihood of serious competition. Even with liberal allowance for increasing competition as cover developed, it is reasonable to postulate that neither site would have reached a 60 percent ground-cover requirement for minimum soil stability within 4 years without the seeding.

[3] *Orr, Howard K. Runoff and erosion trends on two subalpine watersheds in central Utah. 1956. (Unpublished report on file at Intermountain Forest and Range Exp. Sta., U.S. Dep. Agr., Forest Serv., Ogden, Utah.)*

Summary and Conclusions

A September 1959 fire destroyed virtually all of the dominant ponderosa pine forest and understory vegetation on 4,500 acres of sloping watershed land adjacent to the town of Deadwood, South Dakota. Over extensive areas, humus was consumed down to mineral soil.

Emergency rehabilitation measures applied the following spring included aerial application of 11 pounds per acre of a grass-legume seed mixture.

Small plots were installed during the summer of 1960 to study surface runoff and soil erosion trends in relation to establishment of seeded and native vegetation.

Summer storm runoff and sediment production were closely related to a 0.36-inch-per-hour excess rainfall factor. Rates of production per unit of excess rainfall declined significantly each successive year as ground cover developed. Gross rainfall was a poor indicator of both runoff and soil erosion. Snowmelt on frozen ground produced substantial winter runoff at one site, but amounts of sediment were insignificant.

As ground cover developed, summer runoff and erosion rates decelerated until cover density reached about 60 percent (live vegetation plus litter). As ground-cover density increased beyond 60 percent, the rates of surface runoff and sediment production decreased slowly and steadily. It is postulated that total ground cover must equal or exceed about 60 percent density for minimum tolerable runoff control and soil stability. With this criteria as a basis, portions of the burned area were stabilized by developing vegetation within the first growing season, and all of the sampled area was stabilized by the end of the fourth growing season.

Minimum soil stability probably would not have been achieved in four growing seasons on any of the sampled sites without artificial seeding. Seeded timothy dominated the ground cover on stony loam soils throughout the period of study, and seeded Kentucky bluegrass increased to second-place rating. On finer textured soil derived from limestone, smooth brome grass developed more slowly but was codominant with timothy by the end of the fourth growing season. Yellow sweetclover provided significant cover during the first two growing seasons, especially on the finer textured soil, then declined rapidly.

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COMMON AND BOTANICAL NAMES OF PLANTS MENTIONED

COMMON NAME	BOTANICAL NAME AND AUTHOR
SHRUBS	
American red raspberry	*Rubus strigosus* Michx.
Bearberry	*Arctostaphylos uva-ursi* (L.) Spreng.
Common chokecherry	*Prunus virginiana* L.
Common juniper	*Juniperus communis* L.
Creeping mahonia	*Mahonia repens* (Lindl.) G. Don
Rose	*Rosa* sp.
Serviceberry	*Amelanchier* sp.
Snowbrush ceanothus	*Ceanothus velutinus* Dougl.
Spirea	*Spiraea* sp.
TREES	
Ponderosa pine	*Pinus ponderosa* Laws.
LEGUMES	
Hairy vetch	*Vicia villosa* Roth
Yellow sweetclover	*Melilotus officinalis* (L.) Lam.
GRASSES	
Cheatgrass	*Bromus tectorum* L.
Kentucky bluegrass	*Poa pratensis* L.
Smooth brome	*Bromus inermis* Leyss.
Timothy	*Phleum pratense* L.
Wheatgrass	*Agropyron inerme* (Scribn. & Sm.) Rydb.
FORBS	
American dragonhead	*Dracocephalum parviflorum* Nutt.
Aster	*Aster* sp.
Carolina geranium	*Geranium carolinianum* L.
Clematis	*Clematis* sp.
Spreading dogbane	*Apocynum androsaemifolium* L.
Wild lettuce	*Lactuca* sp.

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Orr, Howard K.
1970. Runoff and erosion control by seeded and native vegetation on a forest burn: Black Hills, South Dakota. USDA Forest Serv. Res. Pap. RM-60, 12 p., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

Growth of seeded species in combination with reestablishment of native vegetation reduced overland runoff and soil erosion to tolerable levels within one to four growing seasons. Gross rainfall was a poor indicator of runoff and soil erosion from small plots. Trends were best defined by declining rates of runoff and sediment production per unit of excess rainfall. Sixty percent ground-cover density (live vegetation plus litter) is postulated as the minimum necessary for soil stabilization. This cover density almost certainly could not have been reached within the 4-year study period without seeding. Seeded grasses—timothy and Kentucky bluegrass on coarse-textured soil and timothy and smooth brome on fine-textured soil—were especially important because of their dispersion and abundance, and persistence of litter production.

Key words: Soil stabilization, ground-cover plants, runoff, forest fire control

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Key words: Soil stabilization, ground-cover plants, runoff, forest fire control

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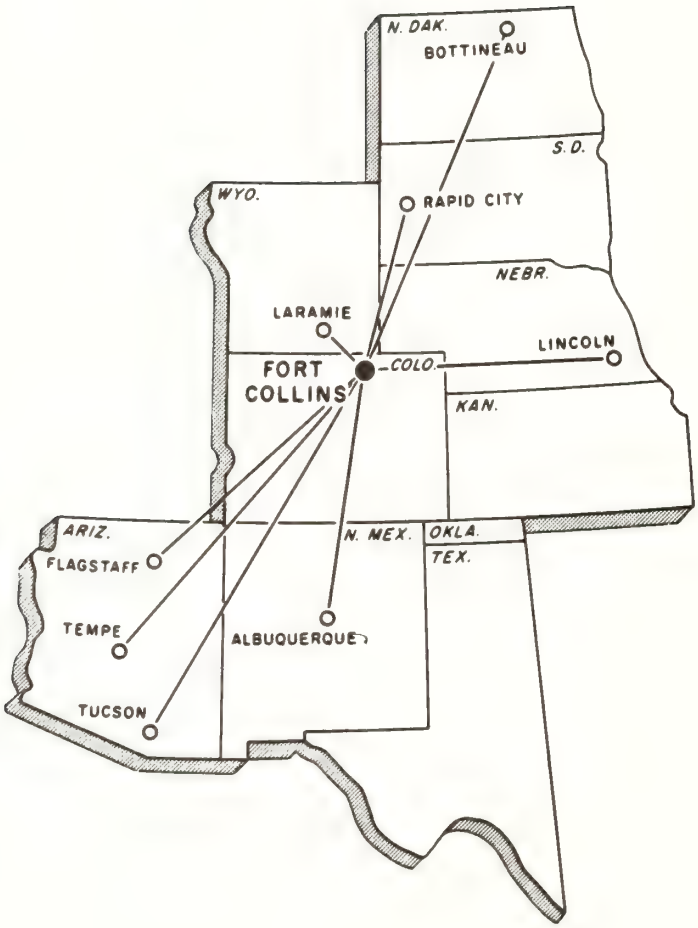
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artillery control of avalanches along mountain highways

Neal C. Gardner
Arthur Judson

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ABSTRACT

Presents planning and operational procedures, and discusses criteria for avalanche control and the evaluation of avalanche hazard based on field data. Outlines a method for determining when gunfire should commence. Gives basic information necessary for formulating operational forecasts for highway maintenance and avalanche control personnel based on: mountain weather forecasts, traffic density, and current snow conditions. Explains instrument needs in detail.

Key words: Avalanches, snow density, anemometers, meteorological instruments, roads.

About the cover:
Sighting an artillery piece on the starting zone of Alta's Superior avalanche, one of several avalanches which threaten the busy highway between Alta and Salt Lake City, Utah. Photo courtesy of E. R. LaChapelle.

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October 1970

Artillery Control of Avalanches along Mountain Highways

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FOREWORD

While practical experience and intuition have been the mainstays of avalanche control operations in the past, the increasing avalanche hazard on mountain highways calls for more reliance on instruments and semiquantitative methods for determining avalanche hazard. Snow is a difficult material to work with because it is constantly changing, and the spatial variations in its physical and mechanical properties are great. Further, it is difficult and sometimes dangerous to make observations and take measurements on snow in avalanche starting zones where such data are most valuable. On the bright side, techniques for evaluating avalanche danger are improving, reliable field instruments are more available than before, and data on weather, snow, and avalanches are now being gathered at some 21 mountain sites in North America. Research personnel are optimistic that the availability of large quantities of good data will eventually lead to useful new evaluation techniques.

Information presented in this Paper will aid field personnel engaged in avalanche operations; the techniques described here were tested and successfully used on a mountain highway in Canada.

Artillery Control of Avalanches Along Mountain Highways

Noel C. Gardner and Arthur Judson

Increasing winter use of mountain highways threatened by avalanches has intensified the need for good avalanche control programs. Although complete protection from avalanches is not economically feasible, a well-planned avalanche defense system including both artillery and structural control provides maximum protection at reasonable cost. Schaerer (1962a, 1962b) explains this well in his publications on the Rogers Pass project in Western Canada. Recent publications by Frutiger (1964), Mellor (1968), and by Frutiger and Martinelli (1966) provide much additional information on structural control.

The purpose of this Paper is to present planning and operational procedures necessary for effective control of highway avalanches by means of artillery; it will show how weather, snow, and avalanche data can be used to determine the timing of gunfire. When control measures are properly timed and applied in a sequence determined by avalanche behavior during past storms, protection from avalanches is achieved with only brief interruptions in traffic flow.

Techniques presented are based on work conducted at the avalanche stations at Rogers Pass, Canada; Berthoud Pass, Colorado; Alta, Utah; and several other locations in the mountainous west. They were operationally tested during the 1962-65 winters at Rogers Pass on the Trans-Canada Highway. Recommended instruments (see appendix B) were field tested at 10 mountain sites in the western United States and at Rogers Pass, Canada. Procedures for establishing blind-firing data were provided by the former chief of avalanche control at the 1960 Winter Olympics.[2]

While the avalanche control problem at Rogers Pass is more complex than at other areas in North America, the concepts treated here can be applied along any transportation route where avalanche hazard is serious. For example, the techniques could be directly applied on Red Mountain Pass in Colorado and on the Granduc access road from Stuart to Tide Lake, British Columbia. With slight modifications, they could be applied at several other locations in the western United States.

[2] *Personal communication with Richard M. Stillman, Rocky Mt. Region, USDA Forest Serv., Denver, Colo.*

The objective of artillery control of avalanches above highways is to artificially release snow accumulations under controlled conditions while traffic is stopped in a safe location. Creating small avalanches that stop short of the road is ideal. This is sometimes possible when highways traverse the runout zone of avalanches; it is not possible when the road intersects avalanches at midtrack level, as they do at many locations in the central Rockies. At such areas, the objective is to artificially release avalanches that produce small amounts of snow on the highway, which can be quickly removed by maintenance equipment.

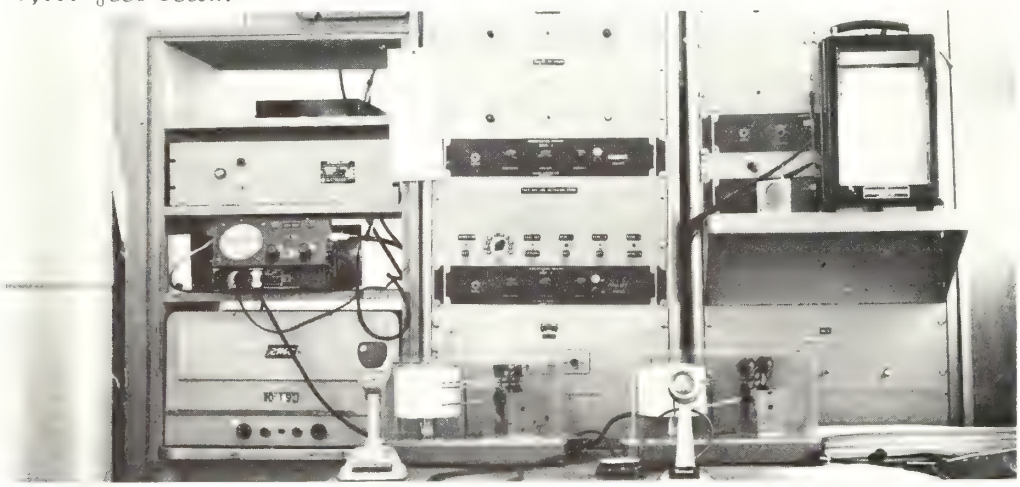
Avalanche hazard on highways can be minimized by an effective artillery program in all but the worst storm conditions. Control programs are considered effective when 95 percent or more of all avalanches affecting the highway are precipitated by gunfire.

Reduction of traffic stoppages due to natural avalanches is important, particularly along stretches where the slide density is high and multiple paths affect the road. For example, near Loveland Pass, Colorado, seven slide paths cross U. S. Highway 6 in one-half mile. The probability that one of these avalanches will strike a moving vehicle is much less than the strike probability for vehicles halted under these slides. For instance, if the fourth avalanche in the group ran across the road, traffic would be stopped on both sides of the obstruction, and cars would be directly exposed to the six remaining avalanches. Using the criterion that when one avalanche falls, others in the same vicinity are likely to follow, the hazard quickly becomes very high. This type of situation occurs frequently on highways where avalanches are uncontrolled, or where control measures are only initiated when traffic density is low and visibility is good. Such control in convenient, and would provide adequate protection if avalanches could be released with any degree of assurance after a certain amount of snow accumulated on the paths, but **slides can only be released when snow is unstable.**

Stability of both new and old snow layers continuously changes in response to variations in temperature and load; instability in snow is often short-lived. For this reason, continuous records on weather and snow conditions are basic to the suc-

Figure 1A.--Base station site at 6,500-foot level on Fidelity Mountain above Rogers Pass, British Columbia. Test field is located just beyond small building in left foreground. Eastern edge of test slope area appears in upper right-hand corner.

Figure 1B.--Main instrument panel inside base station. Multiple registers shown behind microphones on table record windspeed and direction from two remote mountain top sites. Temperature at 8,000-foot elevation near base station is recorded on the strip chart recorder upper right (binary readout). Microphones provide radio transmission to highway maintenance crews at valley location 3,000 feet below.



cess of the control program. When interpreted by an experienced avalanche hazard forecaster, these data make substantial monetary savings possible because of increased efficiency in control operations.

Criteria for avalanche control, avalanche hazard forecasting, and conduct of operations are discussed at length in this Paper. Fundamental considerations include a current mountain weather forecast, information on traffic density, and an evaluation of avalanche hazard based on field data.

I. PRELIMINARY CONSIDERATIONS

Locations for a base forecast station, remote sensing stations, and a level snow study plot must be selected with regard to access and safety. When a forecast area includes more than one climatic zone, additional stations are needed to give representative data on precipitation, temperature, and wind conditions in avalanche areas not represented by the base station instruments. An engineering survey is necessary to establish gun positions and locate targets. This permits gun crews to fire on targets as needed, regardless of visibility.

1. Location of Station and Study Areas

Base Station

The base station (fig. 1) serves as a data collection center where information on weather, snow, avalanches, and traffic density are received and analyzed. It should be centrally located within the avalanche area at an elevation and exposure representative of weather and snow conditions found at the midtrack level of many of the avalanches requiring control. The site should include a level test field 100 feet square suitable for the collection of basic snow and weather data. A small park surrounded by trees that provide shelter from wind is good, if the distance from the base station is not more than 5 minutes' travel on skis. The test field should not be within 200 feet of the nearest building, as snow deposition in such areas is influenced

by local vortices formed by windflow around buildings. Surrounding terrain should include a number of small avalanche-prone test slopes suitable for snow-stability checks during storms. The test slopes should be within one-fourth mile of the base station.

Base station access should be avalanche-free and open for oversnow vehicles even during severe storms. Wands spaced at intervals of 50 feet or less insure safe travel in "white-out" conditions.

Remote Stations

Remote stations are used to sample wind and temperature at starting zone elevations. A location at the head of a catchment basin in the center of the forecast area is desirable. Data can be transmitted to the base station by cable if the distance is less than 2 miles, or by radio telemetry for greater distances (Neal 1962). The number of remote stations needed is dictated by the amount of vertical relief, orientation and complexity of terrain, and size of the forecast area.

Selection of Representative Test Exposures

Avalanche-prone test slopes are selected in the vicinity of the base station. They should represent snow conditions in the starting zones of several avalanches in the forecast area. Exposure, elevation, loading characteristics, and relation to timbered areas are important considerations. Steep slopes (25 to 40 degrees) with several aspects are desirable. Slope distance from top to bottom should not exceed 300 feet for reasons of safety. Safe approach routes are needed. Final test areas should be chosen after the first one or two winters of field work.

2. Planning the Artillery Control Program

Targets

Target selection is time consuming, and requires experienced personnel and up-to-date contour maps; it is facilitated by a collection of good photographs that show the normal winter snow distribution patterns in the starting zones. Pictures showing fracture lines in these zones are especially useful. All significant catchment basins should be surveyed in winter, and again in summer after the snow melts. Select targets where high tensile stress concentrations are expected. Take advantage of convex slope transitions, steeply tilted snowfields beneath cornices, and the flaring of steep gullies. In complex terrain where several starting zones lie at different elevations in an avalanche, locate the primary target on the highest release point, so the avalanching snow will trigger other starting zones as it descends. Care is needed in selecting high-elevation targets to insure that projectiles do not endanger areas beyond the intended impact point.

Two sets of winter photographs are needed. The first set, consisting of aerial obliques, must clearly depict starting zones, tracks, runout zones, and the highway. Selected targets are pinpointed on these photos. A second set of winter photos is taken from proposed gun positions. Targets on aerial obliques are transferred to the gun-position photos. This set is used for training and orientation of gun crews.

Gun Positions

Gun positions are chosen on the basis of crew safety, accessibility, and the number of targets that can be hit from a single location. Firing positions must be safe from avalanches and associated airblast in the worst storm and avalanche conditions. They should be accessible 24 hours a day, pre-

Figure 2.--Circular cement pad on east side of Rogers Pass marks gun site for 105 mm howitzer. Mt. MacDonald in background, rises 6,000 feet above Rogers Pass Highway.

cisely located, and must be easily identified. In the case of mobile weapons, wheel and trail positions are marked at a location along the side of the highway (fig. 2). Extra highway width, 60 feet in length, beyond the normal shoulder provides room for operating mobile guns. Gun positions that permit clear lines of fire to as many targets as possible are best. Firing over structures should be avoided; if it is absolutely necessary, the distance to the furthest structure must be less than two-thirds of the target range (Mellor 1968).

Suitable Weapons

Data obtained from the target and gun location surveys determine the number and type of artillery pieces needed for control. Fundamental considerations include accuracy, safety, range, and mobility. The 75 mm and 105 mm recoilless rifles work especially well where ranges do not exceed 7,000 yards. Both weapons require a two-man team, are highly mobile, and may be mounted in a pickup truck. When fixed mounts are desired, weapons are mounted on a cinderblock tower at a height above the maximum expected snow depth. This allows for backblast clearance, and provides storage space for ammunition inside the tower.

The 75 mm weighs only 167 pounds and is highly accurate up to 2,500 yards. The 700-pound 105-mm recoilless is more reliable at long range (to 7,000 yards), yet retains the accuracy and simplicity of the 75 mm. A shortcoming of this weapon is its limited traverse range (60° against 360° for the 75 mm). A shop modification will correct this inadequacy.[3] The 75 mm pack howitzer is also reliable, easily handled by two men, and is accurate to 9,000 yards. This weapon may be towed behind a pickup truck. Another highly mobile weapon is the commercially available avalauncher. With a range of 2,500 yards, this compressed gas gun can be fired in restricted areas due to its lack of backblast and shrapnel. It is a light weapon (about 200 pounds), costs approximately $600, and unlike most military weapons, is readily available for civilian use. A two-man crew is recommended. The avalauncher has a higher percentage of duds, is less accurate, and lacks the safety of military weapons. Research and development work now being conducted promise to alleviate these drawbacks in the future.

[3] *Personal communication with Richard M. Stillman, Rocky Mt. Region, USDA Forest Serv., Denver, Colo.*

The 105 mm howitzer is recommended when the target range exceeds 9,000 yards. At 5,000 pounds, it is the heaviest weapon approved for avalanche control work. The gun requires at least a five-man crew; eight men are recommended for maximum efficiency. The projectile delivers sufficient shock to either stabilize or release snow in any starting zone. The weapon has a limited traverse range and its mobility is less than desired.

Two fuse settings are available with ammunition supplied for the military weapons discussed here. Fuses can be set with a screwdriver for superquick or 0.05-second delay. The adjustment slot is positioned on the side of the nose cone. Most ammunition is supplied with the superquick fuse setting already made.[3] This results in shell burst on the snow surface, which is desired in most control work. The delayed fuse setting is used when high-strength (hard slab) snow layers are underlain by fragile low-strength (depth hoar) layers deep in the snow cover. The normal procedure in such cases is to use a surface detonation round first, followed immediately by a round with a delayed fuse setting; a reverse order is preferred by some control teams. When the snow cover in a starting zone is exceptionally deep (10 m deep or more) a delayed round followed by a surface detonation is preferred.[3] Cornice control work also calls for use of delayed fuse settings, since an explosion at depth is most effective. Great care must be exercised in shooting cornices, as it is possible for delay-fused rounds to pass through the cornice and detonate as an air burst on the other side.[3]

Blind Firing Data

Blind firing data are recorded when the target area is snow covered so the powder marks can be clearly seen. The weapon is set in position, the target is bore sighted, an initial mil reading is obtained from the gunner's quadrant, and a test round is fired. The first round will fall below the target. The gun is then bore sighted on the powder mark left by the first round, and a new mil reading is taken. The difference between the two mil readings is added to the initial mil setting on the gunner's quadrant. The gun is then elevated to the new setting and a second round is fired. This projectile should be on target. If not, the procedure is repeated, and a third round is fired. A fourth round is seldom necessary. Aiming stakes are placed along the firing line to each target for horizontal control. Firing data for each target are

recorded on waterproof cards, for later use by control teams.

Selection of Traffic Control Points

For safety purposes, all traffic must be blocked from the stretch of highway where artillery is being used. Vehicles are halted in a safe location called a ponding site. These sites should be:

1. Safe from natural avalanches and from sympathetic releases caused by shell bursts within the control area;
2. Large enough to hold all vehicles which will pass the control point in a space of 2 hours;
3. On a grade gentle enough to allow stopping without skidding into vehicles already stopped, and to permit starting without spinning out;
4. As free as possible from drifting snow;
5. Of sufficient width to allow cars and small trucks to turn around in the event of a prolonged delay.

Adequate barriers must be erected at traffic control points. These may be permanent gates that can be easily closed and locked, or portable barriers that can be carried in the back of a half-ton truck and quickly erected across the highway by one man. The barrier must be clearly identified with appropriate color and signing. Warning signs of approach to the roadblock are posted at the entry to the ponding area. Each traffic control area should be manned by a member of the highway department using a radio-equipped four-wheel-drive vehicle. The vehicle should be equipped for towing and winching, and should contain first-aid supplies and avalanche rescue equipment.

II. OBSERVATIONS AND INSTRUMENTATION

Detailed observations on weather, snow, and avalanches are essential to any evaluation of avalanche hazard. Continuity of the data are also important, because methods used to determine when control action should begin depend on continuous records.

3. Data and Instrumentation

Wind

Windspeed and direction should be continuously recorded from an exposed peak or ridge at an elevation and position representative of a large number of starting zones in the control area. Recorders should be located at the base station in a heated room. A rugged wind system that will withstand windspeeds up to 125 m.p.h. under icing conditions is needed. The standard 3-cup S-type (beaded, conical, copper cups) anemometers (fig. 3) are satisfactory and have been used at mountain weather stations throughout the western United States and Canada. Six-hour averages of windspeed and direction are adequate for assessing snow transport into catchment basins, although shorter intervals are used during certain storms.

Figure 3.--Beaded, conical, copper cup, generating anemometer on a 3,810-m mountain summit near Berthoud Pass, Colorado. This is the Weather Bureau Model F-420 windspeed transmitter. The three 300-watt incandescent lamps prevent rime formation on the cups and provide a total radiant flux of 0.5 watt cm^{-2} to anemometer.

Basically, two types of wind systems can be used. One utilizes electrical contacts on both vane and anemometer, and requires from 6 to 12 volts D.C. The vane transmits eight directions and the anemometer each mile of wind travel. An operations event recorder, with a chart speed of 3 inches per hour, contact arc suppressor, and power supply are needed with this arrangement. The other wind system consists of a variable-resistance vane and an anemometer which is a D.C. generator. A twin-channel analog recorder with an internal resistance of 1400 ohms and a 1 milliamp full-scale pen deflection is used to record windspeed and direction. The generating anemometer does not require power, but the vane requires a 5 volt D.C. power supply.

The anemometer circuit utilizes a 5K ohm trim potentiometer in series with the recorder and a 2K ohm trim potentiometer in parallel with the recorder to make it possible to adjust for the resistance offered by long land lines. Both anemometer and vane circuits are fused to protect the recorder from line surges.

The U.S. Weather Bureau's model F-420 anemometer and vane have proven to be reliable in severe mountain weather, and are recommended for the analog wind system. A post-factory modification is needed on this anemometer.[4] The analog wind system gives more complete data than the contact system, although it requires greater technical know-how for calibration and maintenance. Six-hour averages are closely approximated by averaging the first 15 minutes of every other hour from the analog strip chart. Peak gusts are read directly from the chart. A chart speed of 1½ inches per hour is recommended for ease of reading without undue loss of detail.

If cable is used with either system, it should be shielded and either buried or supported on telephone poles at a height exceeding the maximum expected snow depth. A carrier cable is necessary for overhead cables. Icing, lightning, animals, snow creep, water, and bulldozers are common sources of trouble with cable systems.

Anemometers at exposed locations become covered with rime and require infrared heat units; 2.5 cm of soft rime on a cup anemometer reduces rotational velocity by 50 percent at 30 m.p.h. The minimum radiant flux needed to de-ice anemometers under most icing conditions is 0.5 watt per square centimeter. This is provided by 900 watts of radiated power from incandescent lamps (fig. 3) at a distance of 45 cm below the cups (Judson 1969). The cups should be painted a high-gloss black. When 110 volt power is not available and rime is a problem, it is necessary to search for a less exposed site near or below timberline. Relation of wind at this site to that at the more exposed location should be checked by running anemometers at both locations when there is no riming. Other things being equal, tower-mounted ridgecrest anemometers (fig. 4) give better data, are less influenced by local terrain, and are preferred over wind sensors at sheltered sites.

[4]*For details, contact ESSA Weather Bureau Reconditioning Center, Joliet, Ill.*

Figure 4.--Weather Bureau F420-C anemometer and vane on a 10 m series 25 Rhone television tower in the Colorado Rockies. Minimum size of pipe recommended for mounting mountain wind sensors is 1 5/8 inches, outside diameter. Anemometer is elevated to avoid air-flow interference from vane.

Temperature

Air temperature is required from the base station study field. Maximum, minimum, and current temperatures are read every 12 hours from standard liquid-in-glass thermometers mounted in a standard instrument shelter. Additional readings are needed when starting zone elevations are more than 1,000 feet higher than the base station. In this case, temperatures should be transmitted to the base station from remote stations along with wind data (fig. 5). Precalibrated thermistors housed in special radiation shields make good remote temperature sensors. Their output may be recorded on either analog or event recorders. When using the latter, the temperature is read out in binary. Use of remote sensors will determine the elevation of the freezing level during storms that produce rain in lower elevations. Determination of this level is a critical factor in avalanche hazard forecasting.

Precipitation Measurements

Precipitation is measured at the base station test field. Measurements should be representative of conditions at the midtrack level. A recording rain and snow gage with a 7-day clock and an electric chart drive, snowboards, and snow stakes are used. The recording gage provides a continuous record

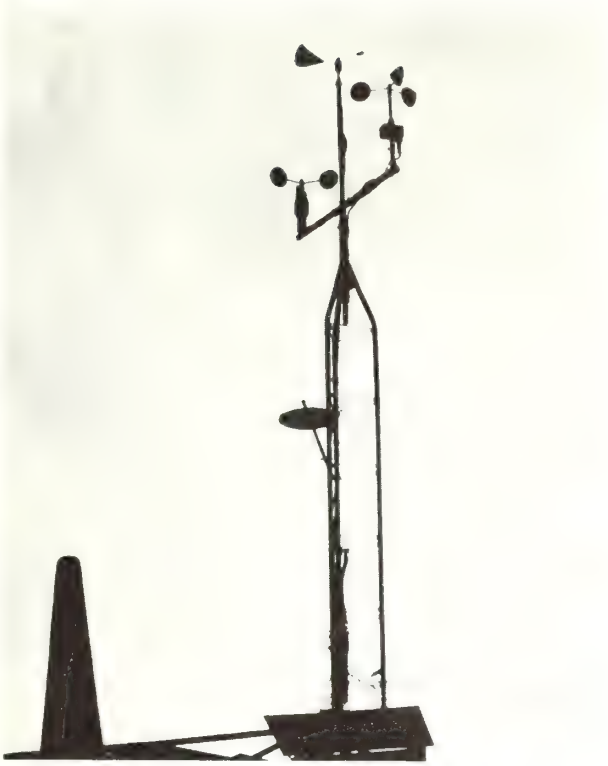


Figure 5.--Wind and temperature sensors at a remote station in the Colorado Rockies. Generating anemometer on left, variable resistance vane center, contact anemometer right, and radiation shield housing thermistor for temperature readings.

of precipitation. The 8-inch can is used as the standard 24-hour precipitation amount for historical records when it is known that rain occurred, or when the water-equivalent core reading determined from the 24-hour snowboard is affected by local drifting.

Four snowboards give additional information needed at the base station. They are portable and have a plywood base with an area of about 1,000 cm^2. Attached to the base is a meter stick reinforced by wood or metal backing. Total snow depth on the ground is read from a permanently anchored snow stake. Height of this stake should exceed the expected maximum snow depth at the site by at least 1 m. All stakes and snowboards are painted white to reduce radiation melting. The four snowboards are clearly labeled to avoid confusion. The first of these is the **storm board**. It is set flush with the snow surface and remains in place until the end of each storm, when it is cleaned and reset flush with the new snow surface. This board gives cumulative new snow depth during storms. It gives valuable information on settlement when compared with other snowboards, if wind has not disturbed the test field. The **24-hour board** is read and reset daily at the same time as temperatures and total snow depth. It is the basis for the daily water equivalent and new snow depth for weather station records. Next is the **interval board**, which is read frequently throughout each storm. Snow cores are taken from this board for each 10 cm of new snow. The board is cleaned and reset flush with the snow surface after each measurement. Readings from the interval board are plotted against storm duration as part of the storm plot. The fourth and last snowboard, called the **shoot board**, is set flush with the snow surface immediately after the first stabilization attempt during a storm. It serves as a reminder of avalanche regeneration during a prolonged storm or a series of small storms. Information from this board alerts the forecaster to the cumulative precipitation rate curve on the storm plot (see Part I of storm plot, fig. 12).

Weight of the new snow in grams per square centimeter (g cm^{-2}), used in evaluating avalanche hazard on the storm plot, is obtained by taking a snow sample or core. An aluminum, thin-wall, open-ended tube with a 3-inch diameter has proven very satisfactory for these measurements, and is easier to handle than an 8-inch can. The tube should be at least 30 cm long, or roughly equivalent to the maximum new snow depth expected in a 12-hour period. To obtain a snow sample, the tube is thrust vertically through the new snow to the base of the snow board. A wide spatula is inserted between the lower end of the tube and the board so the tube and sample can be lifted out. Contents of the tube are dumped in a plastic bag and weighed. Weight in grams divided by the cross-sectional area of the tube in cm^2 gives the required unit.

4. Stability of New Snow

Depth and stability of unsettled snow in an avalanche track are critical factors in avalanche hazard evaluation that usually determine if a moving avalanche has the potential to reach the runout zone with destructive force. This has direct application in planning the control program and to the work schedules of the maintenance crews responsible for keeping mountain roads open.

While it is not possible to apply a definite standard to the stability of an entire slope, it is possible to locate weak layers in new snow deposits and measure shear strength, which provides useful information on snow stability.

Roch (1951) suggested using the ratio of shear strength to computed shear stress as a stability indicator. His approach was primarily oriented toward determining the equilibrium of slabs in avalanche starting zones. By measuring the shear strength (τ_s) with a shear frame, and computing shear stress (τ) as the resultant of the snow weight parallel to the slope, a stability index (R) is obtained for spot locations in the starting zone. When $R = \frac{\tau_s}{\tau}$ is less than 1, a slope is considered unstable. In this case, $\tau = \omega \sin \theta$ where ω is the vertical component of snow weight and θ is the slope angle.

Roch's stability index has much merit, but it presents some problems when applied operationally under field conditions; it is not practical to obtain such data from avalanche slopes on a 24-hour basis. It is also difficult to use the shear frame in snow with densities greater than 200 kilograms per cubic meter (200 kg m^{-3}). [5] Snow densities in starting zones often exceed 200 kg m^{-3}, and forcing the frame into such snow may cause premature collapse or fracturing. Highly erratic readings result.

Field work with shear frames does provide useful information on snow stability in avalanche tracks, when tests are made on an identified weak layer in new snow at the base station test field. Experience at Rogers Pass has shown that a stability index where (s) is the ratio of the measured shear strength of the weakest layer to its overburden pressure ($s = \frac{\tau_s}{\omega}$), provides a useful operational tool in determining the timing of gunfire. When this value is 0.7 or less, and **depth of unsettled snow in avalanche tracks** is equal to or greater than 30 cm, the likelihood of avalanche release is good and slides are expected to run the full track distance. This index is readily obtained at the base station test field during storms, day or night. While it is not implied that identified weak layers found at the base station are everywhere present in the entire avalanche area (especially in starting zones affected by wind), presence of such weak layers indicate existence of similar stratigraphic discontinuities in the avalanche tracks.

[5] 200 kg m^{-3} = 0.20 g cm^{-2} = 20 percent.

Field Procedure - Stability Index

There are four basic steps in the field procedure for determining the stability index for soft slabs: (1) determine the depth of unsettled snow, (2) locate the weakest shear plane in the new snow, (3) measure the shear strength of the weakest layer and the weight acting on it, and (4) divide shear strength by snow weight. Work is done at the base station test field. Depth of the unsettled snow is determined with the first section of a ram penetrometer. Hold it vertically between the thumb and forefinger at the 95 cm mark while the tip of the cone touches the snow surface. The ram is released and allowed to penetrate into the snow. The snow layer penetrated by the ram is the layer to be sampled for stability.

A pit is dug to the depth indicated by the penetration test. Snow samples 30 cm by 30 cm and 30 cm deep, are carefully removed from the pit wall with a thin, square, metal cutting plate. The samples are placed on a tilting platform. After the platform is tilted to an angle of 35 degrees, roughly equivalent to the average gradient in avalanche starting zones, a sharp rap on the base of the platform causes shear failure of the weakest layer, so that the top section falls away (fig. 6). Measure the height of the remaining sample and subtract this from the original 30 cm depth for the shear plane location. This procedure is repeated until all of the snow in the exposed wall has been tested. Although more than one weak layer may be

Figure 6.--Tilt-board and snow sample used to determine the location of a weak shear plane in the surface snow layers at the Rogers Pass base station.

found, the weakest one can usually be detected by observing the character of each failure during testing.

Shear strength of the weakest layer is measured in a newly exposed portion of the pit wall with a 100 cm^2 shear frame (fig. 7). To make this reading:

1. Remove all except the last 4 cm of snow above the shear plane with a spatula.
2. Place the shear frame on the snow above the plane and carefully and slowly press it downward until it rests directly on the weak layer. It is often difficult to place the frame on the weak layer without causing a premature collapse failure on the plane, particularly if the snow immediately above the plane is tough. In such cases, cut through the snow where the shear frame must pass with a sharp, thin-bladed knife before inserting the frame.[6]
3. Hook a 1,000-gram spring balance to the frame and pull steadily in a direction parallel to the weak layer until shear failure occurs (fig. 7).

An average of three readings is taken. Weight of the snow lying above the weak layer can be quickly ascertained by the procedure described earlier for determining the water equivalent of snow on the base station snow boards.

Figure 7.--Using the shear frame in a surface pit. Handle on top of frame allows operator to keep instrument from accelerating after shear failure takes place in hard snow.

[6] *Personal communication with Andre Roch, Swiss Fed. Inst. for Snow and Avalanche Res., Davos, Switz.*

Test Slope Stability

When significant instability is found ($s < 0.7$), or if there are any doubts about stability in the base station test field, additional work is done on the representative test exposures (fig. 8)—if time and weather permit. Snow deposition on the test slopes is monitored by means of **slope stakes** (fig. 9), which are cleaned and reset flush with the snow surface following each storm. Bases of these stakes have the same dimensions as the storm boards. The vertical portion of the slope stake is hinged to permit the base to lie parallel to the slope.

Figure 8.--Observers testing surface snow layers at the "Round Hill" test slopes above base station. Trans Canada Highway in valley 4,000 feet below.

A pit is dug to expose the vertical profile of snow lying above the board, and the pit wall is examined for weak layers. Such layers can be detected by inserting a spatula or a small piece of plastic (about the size of a credit card) vertically

Figure 9.--Slope stake with hinged vertical depth marker in decimeters is used to determine snow loading in the steep starting zone areas of test slopes. Stability data for surface snow layers lying above the base of this board provide useful information on stability of snow at avalanche fracture lines.

at the base of the snow layer and slowly forcing it (with one hand) to cut through to the snow surface above. This is repeated several times until layers with different strengths are delineated. Snow grains in these layers are examined with a 10-power hand lens. Presence of graupel, hoar, degenerated suncrusts, or other loose, cohesionless grains are warning signs of instability, particularly when they appear in defined layers 30 cm or more below the snow surface. Snow grains found in the exposed pit wall are classified according to the physical processes responsible for their formation. Sommerfeld (1969) explains this in his "Classification Outline for Snow on the Ground." Layer thicknesses and height above the sloping snow board are also recorded.

Ram penetration tests made with the new lightweight penetrometer (fig. 10) described by Perla (1969) provide valuable additional data on snow stability, and permit accurate resistance to penetration measurements on low-density snow for the first time. Recent field tests in Utah and Colorado show it is capable of detecting differences in snow strength with densities as low as 70 kg m^{-3}. Ram numbers between 0.1 and 3 kg are measured with ease, whereas measurements with the standard ram were unreliable below 3 kg. The instrument (plus driver) weighs only 200 grams, is easily transported, can be operated by one man, and is quick to use. Procedures for operating the lightweight ram penetrometer follow:

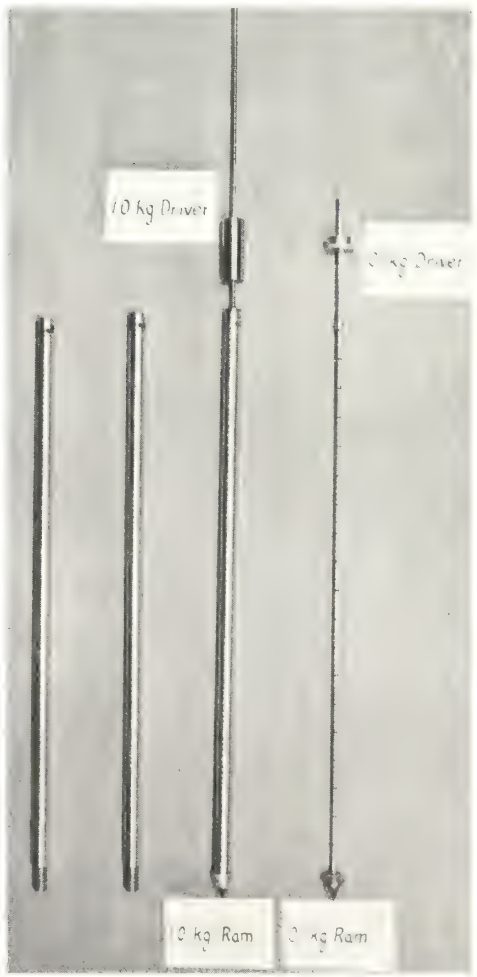


Figure 10.--Standard ram penetrometer with 1 m extensions, left; lightweight ram, right. Both instruments measure resistance to penetration and give an index of mechanical strength of snow.

1. Hold it vertically between thumb and forefinger with the cone tip touching the snow surface.
2. Release, allowing instrument to penetrate into the snow.
3. Read and record depth of penetration.
4. Add the driver, slip it over the guide rod and carefully lower it (while supporting the penetrometer weight with the other hand) until it rests on top of the larger driving shaft.
5. Release, allowing instrument and driver to further penetrate from its position in step 3.
6. Read and record this penetration depth.
7. Raise the driver to the 1 cm mark on the guide rod and release (driver free-falls to top of shaft).
8. Repeat step 6.
9. Repeat step 7.

Steps 6 and 7 are repeated, until the cone reaches harder old snow. Drop height of the driver is increased as needed, and several drops from the same height can be repeated without reading penetration depth, as long as the rate of penetration is uniform and does not exceed 2 cm per drop. Ram numbers (W) are computed, from $W = \frac{Rhx}{d} + R + Q$, where:

R = mass of driver (kg)
h = fall height of driver (cm)
x = number of hammer drops for each (h)
d = net penetration depth
Q= mass of penetrometer (kg)
W= ram number (kg)

Penetration depths in cm are plotted against ram numbers on millimeter cross-section paper, and the points are connected by lines to construct a profile of relative mechanical strength of the layer tested. Changes in snow stability are readily apparent, when such tests are made and plotted at intervals during storms (a 6-hour interval is suggested). Although this instrument has not been operationally tested and is not commercially available at present (the standard 1 kg parent unit, fig. 10, has been available for years), we are impressed with its ease of operation, and believe it to be a worthwhile addition to the limited objective tests currently available to avalanche men in the field.

Test skiing provides further information on slope stability. Presence of tensile stress in soft slabs is detected by observing the reaction of snow in the immediate vicinity of the skis. In the absence of surface crusts, local fractures that extend just 1 or 2 feet in front or to the sides of the skis indicate only slight instability. When such fractures extend many feet from the skis, instability is high and conditions are favorable for avalanche release. Snow is extremely unstable when one is able to release test-slope avalanches merely by approaching them from a distance of 50 to 100 feet above the fracture line.

In lieu of a lightweight ram, the handle end of a ski pole is used to probe test slopes. Presence or absence of well-defined weak layers is felt by changes in the degree of resistance to penetration with depth. In general, moderate to strong resistance to penetration **in old surface layers** (top 10 to 20 cm), with decreasing resistance with depth, indicates instability. Soft slabs (new snow) will not even support the weight of the pole. Determination of slope stability is an art, and there is no substitute for experience. Best information is obtained by combining astute field observation with numerical data provided by instruments.

A three-man team is recommended for work on test slopes. The most experienced one identifies snow structure at the slope stakes and operates field instruments, a second man records data in a waterproof field book, and the third person anchors and belays the other two with 7/16-inch nylon climbing ropes. Ropes are anchored to a tree or belay post above the test slope. Should the slope avalanche (it often will), the men on it shout: "Falling!" to alert the belayer. Rope diameters less than 7/16 inch are not recommended: forces created on the rope by avalanche snow flowing over the rope and attached man can exceed those developed in a 30-foot free-fall! [7]

Use of a packboard-mounted, lightweight test kit (fig. 11) containing field instruments facilitates data collection and allows observers to move quickly from one test area to another.

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[7] *Personal communication with Edward R. LaChapelle, Dep. Atmos. Sci., Univ. Wash., Seattle.*

Figure 11.--Packboard-mounted test kit containing instruments for making strength and stability measurements of snow on test slopes.

III. FORECASTING TECHNIQUE—DRY SNOW

5. The Storm Plot[8]

The storm plot is used to determine the timing of gunfire and the sequence of control operations. It consists of a three-part graphic display of the field data gathered during storms (fig. 12). Part I establishes a relationship between precipitation intensity, cumulative new snow weight, and avalanche occurrence; Part II depicts temperature and wind; and Part III illustrates snow stability, depth of the unsettled snow, and avalanche occurrence.

Part I. The Control Curve

This section of the storm plot utilizes past records of precipitation intensity and avalanche occurrence to predict the onset of current avalanche activity. The control curve depicts cumulative new snow weight as a function of time (fig. 12, Part I). The slope of the curve represents the average cumulative precipitation rate during storms that produce natural avalanching. Critical weight levels for avalanche release are identified on the curve.

At least 5 years of data on precipitation and natural avalanches are needed before a reliable control curve can be made. Twelve-hour precipitation amounts and hourly avalanche release times are used to construct the curve.

The first step in constructing the control curve is to select each storm that caused natural avalanches to approach or block the highway. Plot cumulative new snow weight in g cm^{-2} against storm duration in hours. Make a curve for each storm by connecting the points. Place arrows on each curve to indicate the release time of each avalanche. Identify each snow slide by either entering an abbreviation or a number alongside each arrow. When all data are plotted, fit the control curve (by eye) as an average of the individual curves.

Critical weight levels are now marked on the control curve. Select the earliest avalanche release time (the arrow nearest the Y axis), and extend this arrow vertically until it intersects the control curve. With a pencil, follow the control curve to the left (toward its point of origin) for a distance equivalent to 4 hours on the X axis. Clearly mark this point with a large arrow. **The new snow weight corresponding to this point is the critical weight.** Artillery control should begin when the new snowfall reaches this weight. The 4-hour lead time is used as a safety factor; it allows time to mobilize gun crews in advance of expected avalanche activity, and provides leeway needed to allow peak traffic flows to clear avalanche areas.

The precipitation and avalanche data plotted for Rogers Pass, Canada, showed three distinct avalanche groupings. Avalanches in group I fell during the latter part of the first 24 hours, group II fell between 40 and 50 hours, and group III fell from

[8] *The storm plot was originally conceived by Montgomery M. Atwater to monitor winter storms and avalanche potential at Alta, Utah. Principal modifications in the author's version include the control curve, critical weight concepts, and the stability index.*

84 to 96 hours after storms began. Although there was some overlapping of groups, the avalanche pattern was sufficiently distinct to warrant identification of a critical weight for each group:

Avalanche frequency group	Critical weight g cm^{-2}	Hours since storm began
I	2.5	20
II	3.6	36
III	5.5	80

The existence of three avalanche frequency groups at Rogers Pass was a lucky find, because it simplified the control job. Crews could concentrate on the most sensitive avalanches in the early stages of a storm, and did not have to worry about the 50 avalanches in groups II and III until later (there were 80 avalanches in 27 miles of the three-lane road).

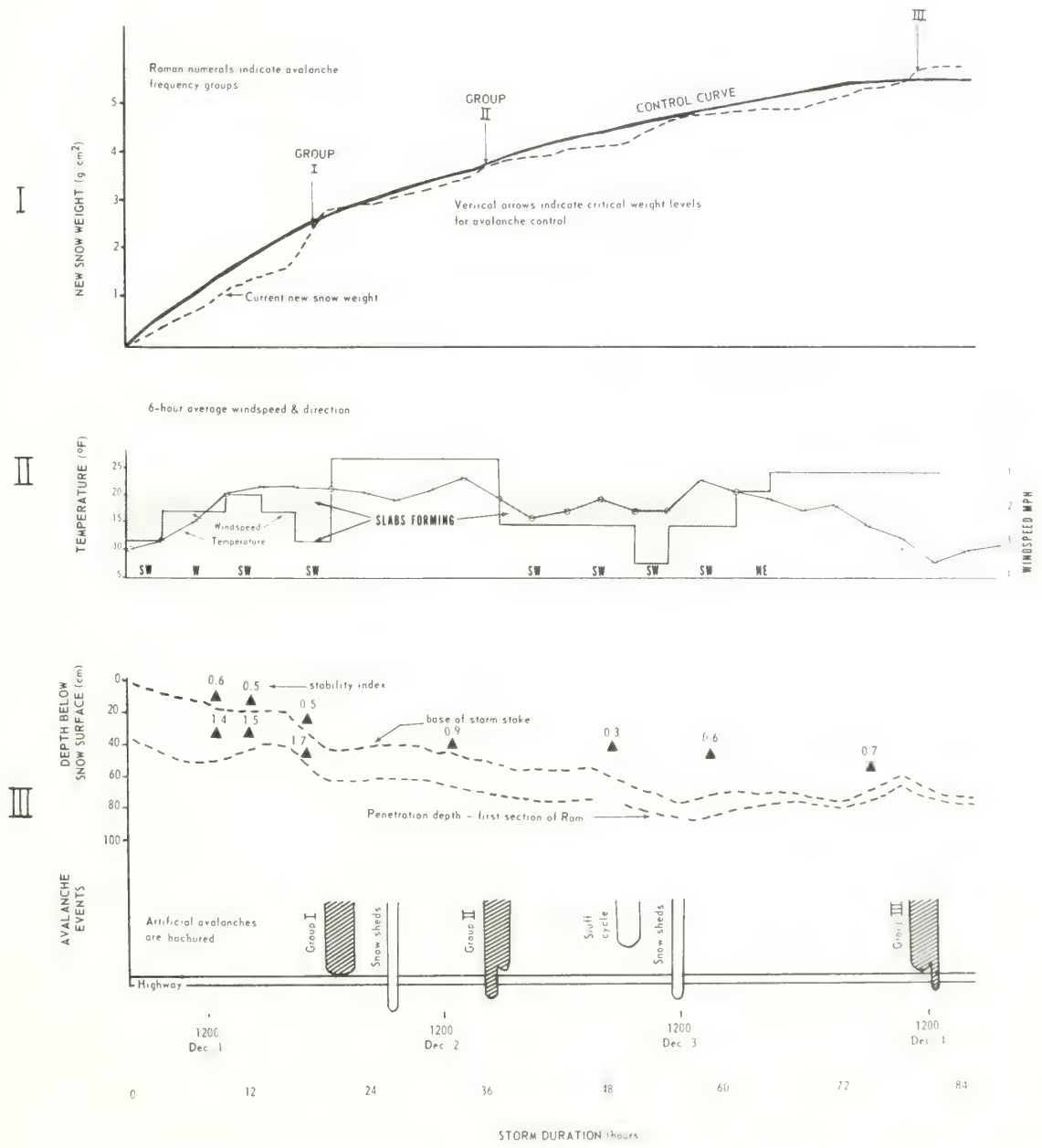

Figure 12.--Storm plot for evaluation of current avalanche hazard. Field data on weather, snow and avalanches are plotted and kept current during storms.

A good deal of scatter was found when this plotting technique was applied to data from Berthoud and Loveland Passes in Colorado. Avalanches did not appear in well-defined frequency groups, although the onset of slide activity during large storms was well defined. Stratification of the Colorado data into low-intensity and high-intensity storms produced critical weights of 2.7 g cm^{-2} in 46 hours and 2.2 g cm^{-2} in 16 hours for the respective types (fig. 13). Low-intensity storms averaged 0.02 inch water equivalent per hour (in hr^{-1}) and high-intensity storms averaged 0.05 in hr^{-1} for this set of data. Light snow fall, and the combination of high wind and expansive flat areas above timberline upwind from starting zones (all of which favor heavy transport) add to the scatter in the Colorado data.

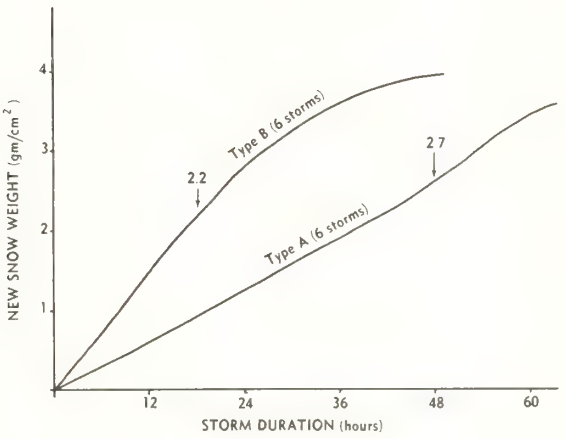

Figure 13.--Control curves for determining onset of avalanche control measures for low (type A) and high (type B) intensity storms. Data for Loveland and Berthoud Passes in Colorado.

Another factor which prevented a valid test of avalanche frequency response to cumulative new snow weight in the Berthoud and Loveland Pass data was the constraint of having to use natural avalanches that occurred between control applications applied by the Colorado Highway Department. Such control applications, even though not rigorously applied, do affect avalanche response. Also, large storms that are required to produce the less frequent avalanches in groups II and III on the control curve are rare events in this section of Colorado (Judson 1965). The authors feel that Part I of the storm plot, the control curve, is most applicable in areas where average precipitation intensities during avalanche-producing storms exceed 0.05 in hr^{-1}. Winter precipitation intensities equal to or greater than 0.05 in hr^{-1} are common at the following highway avalanche areas: Alta, Utah; Red Mountain and Wolf Creek Passes in Colorado; Granduc Mine and Rogers Pass, British Columbia. The control curve is, nonetheless, a useful aid in planning control programs even in low-intensity precipitation areas such as Colorado's Berthoud and Loveland Passes.

The control curve and critical weight levels are etched on a piece of stiff transparent plastic, which is used as an overlay for current storm plots of cumulative new snow weight against storm duration. New snow weights are plotted for each 10 cm of new snow from the base station interval stake during storms. Special attention is given to the **rate** at which the cumulative new snow weight approaches each critical weight level on the control curve, for this determines whether the decision to start control must be initiated prior to or at some time later than the time indicated by the frequency-group arrows. Information from the two other parts of the storm plot must also be considered at this point before any decisions are made.

Part II. Temperature and Wind Limitations

Wind and temperature during a major storm influence the amount and type of snow deposited in starting zones. Experience at instrumented avalanche stations shows that winds between 15 and 30 m.p.h., when accompanied by new snow and temperatures between 10° F. and 30° F. often cause widespread formation of unstable soft slabs (stippled area, fig. 12, Part II) in avalanche starting zones. Presence of soft slabs favors avalanche release by artillery because they have (1) a high degree of internal cohesion, and (2) relatively high stress concentrations, which allow rapid propagation of fractures initiated by explosives.

Six-hour averages of windspeed, wind direction, and temperature from remote stations are plotted in Part II of the storm plot. Wind direction during storms is also important because it determines what slopes will receive snow deposition. During some high-intensity snowfalls, slabs form on all slopes, regardless of wind direction or slope orientation. Such conditions occur from combination falls of rimed spatial dendrites, needles, and graupel. LaChapelle's (1969) Field Guide, written especially for avalanche men, presents excellent illustrations

of new snow crystals. We recommend this book.

Part III. Track Stability, Snow Depth, and Avalanche Occurrence

Data from stability tests made at the base station and on the test slopes are utilized in this section, along with snow depth and avalanche occurrence. New snow depth read from the storm board, and total depth of the unsettled track snow determined by penetration tests, are plotted against storm duration. Stability indexes, shown above the triangles on figure 15, are plotted to show the location of the weakest layer in relation to the snow surface. The total depth of unsettled snow, determined by the penetration depth of the first section of the ram, gives the amount of track snow that is likely to become incorporated in a moving avalanche.

All natural and artificial avalanches of any significance are plotted at the bottom of the storm plot to show the location of avalanche debris relative to the highway.

6. Using the Storm Plot

The total storm plot, with all three parts, can only be used as an aid in determining when to initiate control action during major storms, for it was designed for use in situations involving direct-action soft-slab avalanches. At a glance of the forecaster's eye, it gives an instant summation of the current avalanche potential and a summary of events leading to the current situation—something not possible by memory alone. Successful implementation still depends heavily on experience and intuition because many variables known to affect avalanche release are extremely difficult to measure under field conditions. Every avalanche man knows that conditions days, weeks, or even months prior to the onset of a major storm will affect the response of avalanches to a given storm. The availability of an unbroken and detailed record of weather and snow conditions affecting the control area prior to each storm is therefore essential.

Parts II and III of the storm plot can be used without modification at most avalanche areas in North America. The shape of the control curve and the critical weight levels (Part I) for determining the onset of avalanche control operations will change from one area to another. For instance, control curves for avalanche areas along the West Coast are expected to reflect the higher precipitation intensities associated with winter storms there in contrast to relatively low intensities found in the mountains of northern Colorado and Wyoming. The degree to which these differences will affect placement of critical weight arrows remains to be seen. It is worth noting that precipitation amounts given by Atwater (1952), Poggi and Plas (1966), and Judson (1967)—which initiate widespread avalanching in Utah, the French Alps, and the Colorado Rockies, respectively—coincide with the 2.5 g cm^{-2} weight level on the Rogers Pass storm plot. On the basis of these data, one can reasonable assume that the first critical weight level for sensitive avalanches (Group I) at most areas will be in the vicinity of 2.5 grams.

The situation for releasing avalanches by artillery fire is ideal when (1) cumulative new snow weight in Part I of the storm plot approaches or exceeds the control curve at the critical weight levels indicated by the arrows, (2) conditions specified in Part II are met, (3) snow stability in Part III is ≤ 0.7, and (4) unsettled track snow is ≥ 30 cm. If critical weight levels are reached or approached prior to the time indicated on the control curve, artillery control is initiated earlier than indicated; for lower precipitation rates, gunfire is delayed.

Special Cases

Snow accumulating in either catchment basins or avalanche tracks prior to onset of a major storm will influence the timing of control action for all avalanche groups unless this snow is stabilized by settlement. Results of test skiing (U. S. Forest Service 1961) plus an analysis of the surface snow layers on the test slope stakes determines what timing adjustments are required. Recognizable remnants of new snow crystals such as stellar arms and thin platelike fragments, or presence of small needlelike splinters indicate a lack of stabilization. If there is still unstable snow on the slopes at the onset of a major storm, the total weight of snow considered unstable on the slope stakes is added to the snow weight for the present storm. Avalanches are controlled when the total snow weight equals the critical weight levels for each group (Group I = 2.5 g, etc.).

If a storm terminates before the new snow weight reaches the critical weight levels of the second or third avalanche groups, it is necessary to control Groups II and III before settlement occurs.

The chances of releasing most of these slides still remain high, although it is unlikely they will run the full length of their tracks.

A very dangerous avalanche situation arises when soft slab forms in the absence of wind, because all exposures are affected. This condition is initiated by a fall of pure needle crystals, rimed spatial dendrites, or graupel, after the accumulation exceeds 15 cm. Astute observation of new snow crystals and of surface snow reaction to test skiing during such storms is necessary. Deep falls of loose snow composed of clustered dendrites, plates, or stellar or irregular crystals usually do not result in initial soft slab avalanches if these crystals fall when windspeeds are less than 12 to 15 m.p.h. After new snow depth approaches or exceeds 60 cm., however, avalanches composed of loose snow may be expected. Hazard develops quickly in this situation with an increase in windspeed, even after snowfall has ended. Artillery fire should commence within 2 hours following an increase in wind if the new snow weight approaches or exceeds any of the critical weight levels.

Gusty winds in excess of 30 m.p.h. create erratic deposition patterns. Snow transported away from the usual fracture-line positions is deposited only in the most sheltered areas. In such cases, projectiles are fired into the lower portions of the starting zones and in upper sections of the avalanche tracks in addition to the regular targets.

Similar target adjustments may be required during storms when temperatures are above 25° F. and windspeed is marginal (12-18 m.p.h.), particularly when the starting zone is exposed to sun for an hour or two prior to artillery fire. Projectiles are fired into areas below the normal release points in these cases. Experience shows best results are obtained when shots are placed in shaded steep sections of the track.

Extremely low stability indexes (s = 0.2-0.4) in the track snow dictate early artillery control, otherwise large volumes of snow reach the highway due to the increased descent speed of the avalanches. Such low stability indexes are sometimes caused by weak layers of surface hoar, pure graupel, or other loose, cohesionless grains such as depth hoar.

Rain on snow is a unique case precluding use of the storm plot, particularly when rain falls on fresh, cold snow. If special weather forecasts give adequate warning, **shoot every target in the control area before the rain begins.**

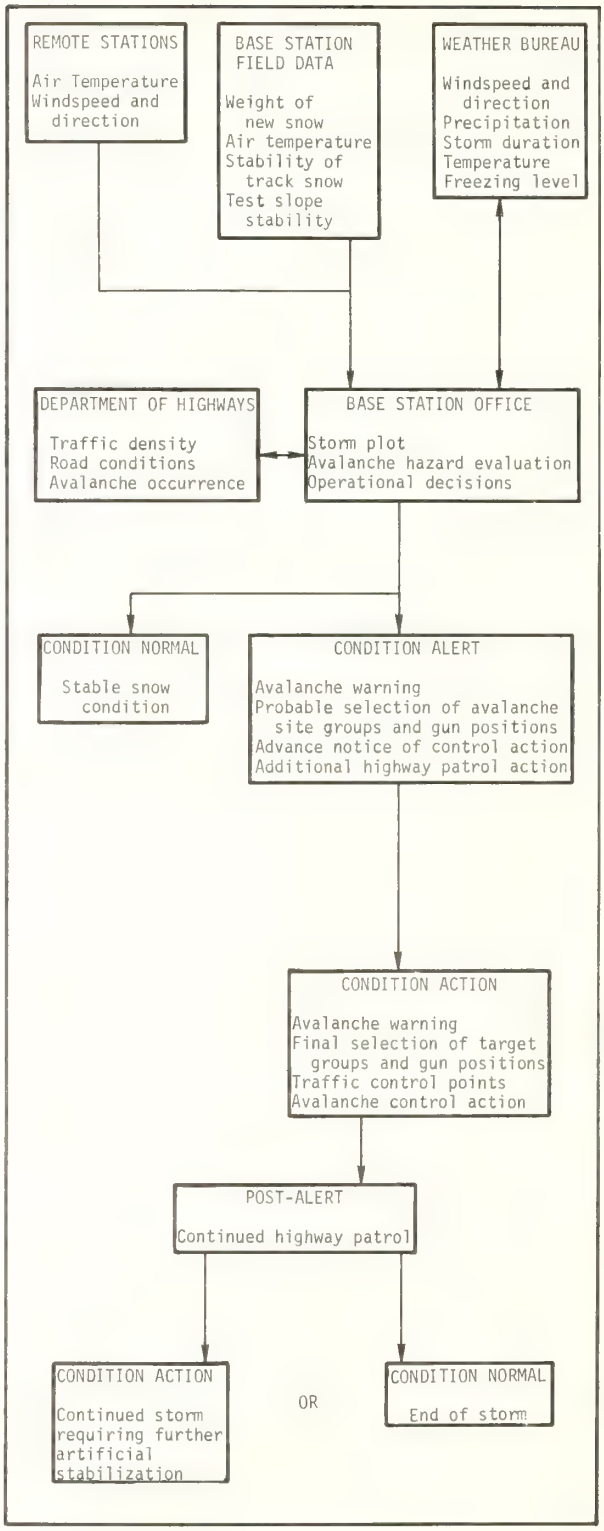

Figure 14.--Operations flow chart of the avalanche forecast unit at Rogers Pass, British Columbia.

7. Issuing the Forecast

Forecasts are issued on the basis of information from the latest available mountain weather forecast, the storm plot, and the highway patrol's estimate of traffic density (fig. 14).

Weather Forecasts

A reasonably accurate mountain weather forecast is needed before an avalanche hazard forecast is issued. Weather forecasts can be received from any of the main Weather Bureau forecast centers such as Vancouver, Seattle, San Francisco, Calgary, Salt Lake City, or Denver. Weather forecasts should be received every 12 hours, and should contain the following information:

1. A general summary of current synoptic conditions.
2. Duration and intensity of expected precipitation.
3. Windspeed and direction in the free air at a level within 1,000 feet of most of the starting zones in the control area.
4. Expected temperatures at starting-zone elevations.
5. Elevation of freezing levels (there is often more than one).
6. A report of storm behavior at mountain stations upstream along the storm track.

Before the Weather Bureau forecast centers can issue their forecasts, they need the following observations from the mountain every 12 hours:

1. State of weather: cloudy, partly cloudy, snow, snow flurries, etc.
2. Height of cloud base and trend (rising, no change, lowering).
3. Maximum, minimum, and current temperature, and dew point.
4. 12-hour precipitation—both water equivalent and new snow depth.
5. Precipitation intensity and trend.
6. Windspeed and direction during the past 6 hours from the remote stations.
7. Pressure tendency.

Weather Bureau personnel are not normally charged with the responsibility of making mountain weather forecasts, but they will, if requested. Such forecasts are very difficult to make because of the scarcity of reporting stations in the mountains and the lack of forecasters familiar with mountain weather conditions. Daily contact with weather forecasters will help improve forecasts. When possible, these men should be brought to the mountain station where forecasts are needed. Mutual problems can be discussed, and the weather forecaster can gain useful background information by seeing instrument locations and terrain.

Although teletype, telephone, or radio-telephone can be used for communications with the nearest forecast center, teletype services are recommended because a permanent record of all transmissions is readily available, and forecasts can be transmitted to the base station when observers are out on other jobs. A radio-telephone serves as a backup when land lines are out of service during and following severe storms.

Traffic Density

Peak traffic flows usually follow in some recognizable pattern which can be anticipated in advance. Since congested periods seldom last more than 2 hours, it is often possible to delay control work until traffic peaks pass the avalanche area. This minimizes the number of people affected by temporary road closures, and simplifies traffic control during stabilization programs. Because critical weight levels on the control curve are placed 4 hours prior to the first avalanche event, there is some leeway to allow for periods of heavy traffic. Peak flows are anticipated by contacting state police and highway maintenance crews for a distance of 100 miles on either side of the control area. Snowfall intensity, wind, temperature, and snow stability dictate how much leeway the forecaster has.

Format, Forms, and Dissemination of the Forecast

Control decisions for action and safety measures are written clearly and concisely at the base station on standard forms. This information is transmitted by phone or radio-telephone to highway maintenance personnel responsible for carrying out control; they, in turn, write the information on identical forms at the headquarters maintenance station. This information should be read back to the base station word-for-word, to make sure the correct information has been received. Color-coded forms, each representing a specific type of forecast, are recommended to avoid confusion. We refer to the forms as: ALL-CLEAR, ALERT, and ACTION.

An ALL-CLEAR is issued when snow conditions are stable. It enables maintenance men to plan ahead for jobs requiring men and heavy equipment that might otherwise be tied up in standby or avalanche-clearing operations.

The ALERT form is issued several hours prior to anticipated highway closure. It warns of a mounting avalanche hazard, and shows when and where artillery will be used. In addition, the ALERT form notifies maintenance crews when extra patrol action is needed, and when snow removal is required at gun sites. The type of weapon to be used and the number of shells needed are also specified.

The ACTION form is issued about 1 hour before the gun should go into action, which is sufficient time to ready previously alerted gun crews. An evaluation of the prevailing avalanche hazard is posted at the same time, and the location and sequence of traffic blocks is laid out so all danger zones will be clear of traffic and snowplows during the stabilization program. The sequence of gun positions is outlined and traffic clearing periods are indicated. What gun or guns are to be used is given as well as the number of rounds of ammunition required.

After the first stabilization program is completed during continuous storms, the ALERT form is again issued to show the reduction of avalanche hazard. The required weapon and likely gun positions are again stated when another action period is anticipated. An ALL-CLEAR is issued when the storm subsides and the stabilization program is considered successful.

IV. CONSIDERATIONS FOR WET SNOW AVALANCHES

Wet snow avalanches present a special problem for highways because artillery control is generally ineffective unless soft slab is present. In both Canada and the United States, gun crews confirm the fact that explosive control measures applied to wet snow seldom produce results. There are two possible explanations: (1) isometric grains in a wet snowpack suppress shock wave propagation due to their large grain size and the lack of intergranular bonding; and (2) rapid creep in isothermal snow quickly relieves stresses and prevents dangerous slab conditions from developing.[9] Wet-slab avalanches do occur under natural conditions, however. Regardless of the character of release (loose or slab), wet slides of major proportions present a difficult snow removal problem because they penetrate to the ground and deposit large amounts of mud, rocks, and trees on the highway. Forecast bulletins warning of impending hazard are the only safeguards.

Rain falling on cold, fresh snow is the most common cause of wet avalanches in winter. Presence of an impermeable layer beneath the new snow accentuates the problem; dangerously unstable conditions develop when the snow becomes saturated and the layer is lubricated. Data on the amount of rain needed to initiate avalanches under these conditions are scarce, but forecasters at Squaw Valley, California, feel at least 1 inch is necessary.[10] Recent data from stations in western Washington tend to confirm the 1-inch value as a minimum.

Rain affects snow in several ways: it reduces strength by weakening intergranular bonds, increases density and weight, and warms snow to 0° C. Because warming is a general requirement for wet slides, temperature profiles in surface layers indicate approaching hazard. Current avalanche activity is the most reliable guide to hazard conditions. This information is radioed to the base station by highway maintenance patrols. Information on expected changes in the freezing level (in the free air) provided by the Weather Bureau is also needed.

In spring, large wet avalanches may occur when the entire snow cover from the midtrack level to the valley floor is warmed to 0° C. and snow depth in the track is greater than 1 m. Progressive warming of the snow cover should be monitored by digging full-depth pits and taking temperature profiles at the midtrack level. South exposures are checked first. Minimum temperatures are found in the middle of the pack, as heat is being added to lower layers from the soil and to the upper layers by radiation. When snow becomes isothermal at 0° C. at the midtrack level on south exposures, additional temperature profiles are taken on east, west, and north exposures in that order.

Snow conditions in the first meter below the snow surface signal the onset of wet avalanches after snow becomes isothermal. A fall of new snow, 25 cm. or more in depth, often causes wet slides. If soft slab is present in starting zones (determined by checking test slopes), artillery con-

[9] *Personal communication with Edward R. LaChapelle, Dep. Atmos. Sci., Univ. Wash., Seattle.*

[10] *Personal communication with Richard M. Stillman, Rocky Mt. Region, USDA Forest Serv., Denver, Colo.*

trol is used. The sequence of control is based on snow conditions at the test slopes and in the avalanche tracks. For instance, if soft slabs are found on east exposures and snow cover (to the ground) is isothermal only on south-facing tracks, then avalanches with east-facing starting zones and south-facing tracks are shot first. If soft slabs are present everywhere, control priority is based on frequency groups on the control curve—the same as in winter. The worst situation arises when a deposit of new snow fails to "slab up"—if followed by a warm, suuny day. The strong input of heat often releases avalanches, and because the track snow is isothermal, much, if not all, of it will be incorporated in the flow. Large quantities of avalanche snow reach the highway in such cases.

Wet avalanches may also occur in old snow when an ice layer, 30 cm or more below the surface, acts as a dam to the intrusion of melt water. Saturation of the large-grained old snow above the ice layer leads to avalanching, particularly in the absence of a strong surface crust. Such crusts usually form overnight, and disintegrate in the morning due to heating. A relationship between the deterioration of such crusts (when a buried ice layer exists with saturated snow resting on it) and the onset of spring avalanches was developed from the early studies at Rogers Pass:

1. No surface crust. Avalanches start as early as 0800 hours on southeast exposures, 1000 hours on south exposures, 1200 hours on southwest exposures, and 1700 hours on west exposures.

2. Moderately strong surface crust, 3 to 5 cm. thick. Resistance to penetration 2 to 4 kg (may break when a person walks on it). Avalanches on southeast exposures may begin at 1000 hours. Most avalanches fall between 1130 and 1500 hours on southeast, south, and southwest exposures. Some avalanches are expected on west-facing slopes until 1800 hours.

3. Strong surface crust, 8 to 14 cm thick. Resistance to penetration 6 to 10 kg. (will support a person). Avalanches are unlikely before 1400 hours, and then with only moderate frequency and only on south and southwest exposures.

Deterioration of surface crusts, when present, should be checked at 2-hour intervals beginning at 0700. A warning is issued when the effective thickness of surface crusts decreases to 5 cm. (avalanches begin when the crust disintegrates).

The best deterrent to the large, wet avalanches of spring, is a rigorously applied and carefully planned control program during winter to reduce snow depth in the tracks.

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APPENDIX A

STORM PLOT AND NOTES ON A SEVERE STORM --- 22

APPENDIX B

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STORM PLOT AND NOTES ON A SEVERE STORM

The following information is presented for persons or agencies who are now, or soon will be, charged with the responsibility of operating an avalanche control program where numerous avalanches, falling from several aspects, affect major highway travel. Artillery control of avalanches at such areas is a complicated matter that requires an organized program and a well-trained forecast staff. A three-man team (two professionals and one technician) is considered the absolute minimum for the forecast unit. The man in charge should have at least 5 years' experience with snow and avalanche forecasting. Preferably, he should have a background in synoptic meteorology, snow physics, and hydrology. His assistant should have at least 3 years' experience in avalanche hazard forecasting and control. A background in hydrology or glaciology is desired. All three men should be competent ski mountaineers. The technician should be sufficiently trained in electronics and instrumentation to install, troubleshoot, and repair all instruments required on the project.

Figure 15 presents a storm plot made at Rogers Pass during a severe and prolonged storm which lasted 156 hours. Forecasts issued during the first 24 hours of this storm are reproduced here to serve as an example of the program in action:

Storm start: 0600 hours January 26

0700 January 26: Forecast FORM ONE (ALL-CLEAR) issued to indicate no expected avalanche activity for at least 12 hours. Forecast from Vancouver Weather Office calls for light snow.

1900 January 26: Storm increases in intensity. Weather forecast indicates snowfall to continue for several hours. Avalanches not expected for 2 more hours (see extension listed on Forecast FORM ONE), based on control curve data.

2100 January 26: Continued heavy snow (see cumulative snow weight and control curve) with wind, temperature, and track snow stability favorable for avalanches, prompts a forecast (ALERT) that control of Group I avalanches will be necessary by 2400 hours or shortly thereafter.

0030 January 27: Storm continues unabated. FORM THREE (ACTION) is issued for artillery control to commence in 1 hour.

0330 January 27: Temporary letup in snowfall occurs but weather forecast calls for storm to continue. Increasing wind with track stability index very low indicates control of Group II avalanches will be necessary before the critical weight for that group is reached.

0700 January 27: Very low stability index of 0.4 with increasing wind and snow at favorable temperature results in decision to control Group II slide at 0800 hours.

1200 January 27: Good stabilization has been achieved within control area. Decrease in wind and increase in track snow stability indicates only low to moderate hazard for the next 30 hours.

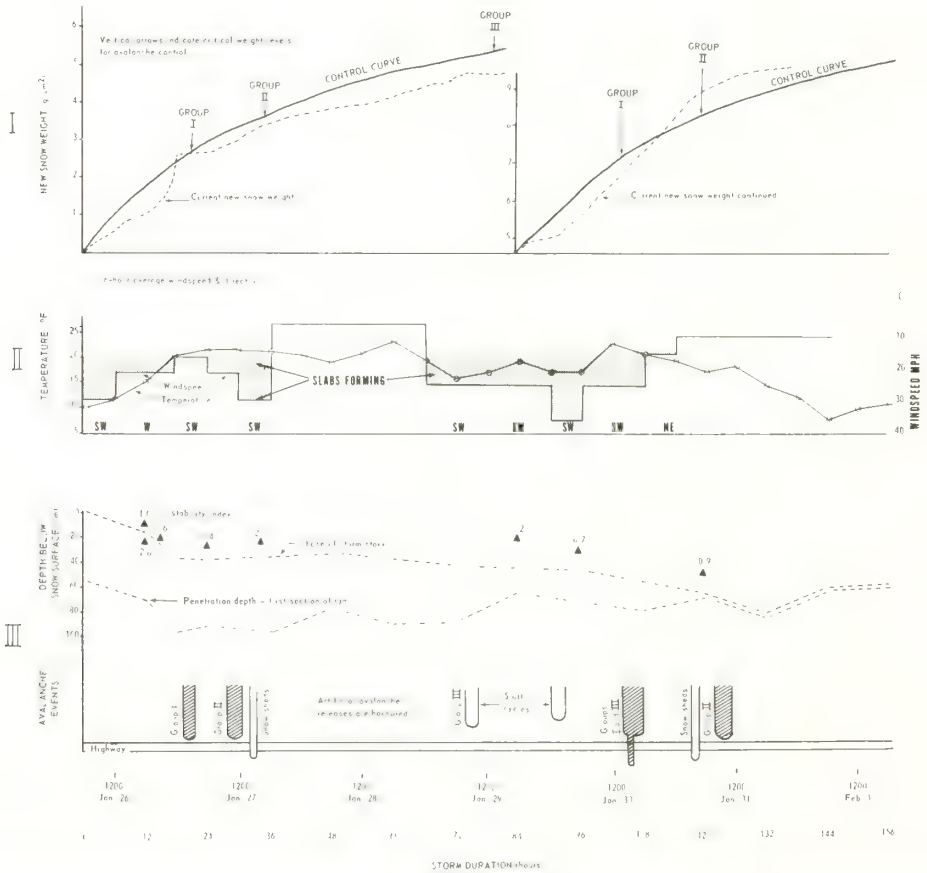

Figure 15.--Storm plot of a severe winter storm at Rogers Pass in 1965. Graphic display of incoming data aids in making avalanche and traffic control decisions along a 27-mile stretch of the Trans-Canada Highway through the Selkirk Mountains.

(FORM ONE)

A L L - C L E A R

ISSUED AT 0700 HRS January 26 (Date)

ISSUED BY Noel C. Gardner

RECEIVED BY R.A. Smith

For the next 12 hours it is not expected that high level snow conditions will produce avalanche activity effective to the highway, nor is artificial stabilization indicated during the interval given above or periods of extension listed below.

EXTENSIONS

Issued at	For approx.	Received by
1900 hrs.	2 hrs.	
____ hrs.	____ hrs.	
____ hrs.	____ hrs.	
____ hrs.	____ hrs.	
____ hrs.	____ hrs.	
____ hrs.	____ hrs.	

(FORM TWO)

A L E R T

ISSUED AT 2100 HRS January 26 (Date)

ISSUED BY Noel C. Gardner

RECEIVED BY R.A Smith

1. AVALANCHE WARNING

Minor Dry Avalanche activity is expected within the next 6 hours.

2. EXTRA HIGHWAY PATROL IS REQUIRED BETWEEN:

MILEAGES: 10 mi. and 14 mi.

3. ARTILLERY FIRE MAY BE REQUIRED BETWEEN:

2400 January 26 hrs. and 0400 January 27 hrs.

4. GUN POSITIONS LIKELY TO BE REQUIRED ARE:

2, 3, 8

(FORM THREE)

A C T I O N

ISSUED AT 0030 HRS January 27 (Date)

ISSUED BY Noel C. Gardner

RECEIVED BY R.A. Smith

1. ARTILLERY FIRE SHOULD COMMENCE AT: 0130 hrs. January 27 (Date)

2. ARTILLERY PIECE AND AMMUNITION REQUIRED:

105 mm Howitzer X and 15 Rounds

75 mm Howitzer ____ and ____ Rounds

3. PROGRAM:

GROUP NO.	PONDING SITE	TRAFFIC DELAY	GUN POSITION
1	1 & 2	40 mins.	2 & 3
____	2 & 3	20 Mins.	8
____	____	____	____
____	____	____	____

4. ACTION:

GUN POSITION	AVALANCHE SITE	TARGET	REMARKS
2	14	1	Avalanche ½ path
____	____	2	Detonation heard
3	15, 16	1	" "
8	37	2	Avalanche to edge of highway
____	38	3	Avalanche to within 100' of hwy
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____

(FORM TWO)

A L E R T

ISSUED AT 0330 HRS January 27 (Date)

ISSUED BY Noel C. Gardner

RECEIVED BY R.A. Smith

1. AVALANCHE WARNING

Reasonable stabilization has been achieved. The likelihood of minor avalanche activity at sites as yet uncontrolled remains.

2. EXTRA HIGHWAY PATROL IS REQUIRED BETWEEN:

MILEAGES: _____ mi. and _____ mi.

3. ARTILLERY FIRE MAY BE REQUIRED BETWEEN:

0600 hrs. and 1200 hrs.

4. GUN POSITIONS LIKELY TO BE REQUIRED ARE:

2, 3, 4, 5, 6, 8

(FORM THREE)

A C T I O N

ISSUED AT 0700 HRS January 27 (Date)

ISSUED BY Noel C. Gardner

RECEIVED BY R.A. Smith

1. ARTILLERY FIRE SHOULD COMMENCE AT: 0800 hrs. January 27 (Date)

2. ARTILLERY PIECE AND AMMUNITION REQUIRED:

105 mm Howitzer X and 25 Rounds

75 mm Howitzer ___ and ___ Rounds

3. PROGRAM:

GROUP NO.	PONDING SITE	TRAFFIC DELAY	GUN POSITION
2	1 & 2	50 min.	2
	2 & 3	1 hr. 5 min.	4
			3
			5
			6
	3 & 4		8

4. ACTION:

GUN POSITION	AVALANCHE SITE	TARGET	REMARKS
2	12	2	Detonation heard
		3	Sound of avalanching snow
4	17	1	Detonation heard
		2	Avalanche into mound defenses
4	17	3	Detonation heard
		4	" "
3	12	1	" "
	12	2	Avalanche within 300' of hwy.
	10	1	" " 100' " "
	10	2	Detonation heard
5	20	3	" "
	20	4	Avalanche within 200' of hwy.
6	23	2	" " 400' " "
	24	1	Detonation heard
	25	2	" "
	26	1	" "
	28	1	Avalanche within 400' of hwy.
8	32-35	all	Small slides, stopped above hwy.

APPENDIX B

INSTRUMENTATION

Numerous instruments needed for avalanche work have been field tested at avalanche stations in the mountain west. The essential instruments are listed here, along with a commercial model of each that has proved reliable under typically severe field conditions.[11]

I. WINDSPEED AND DIRECTION

A. ANALOG SYSTEM

Item	Source
1. Windspeed transmitter F420-C, modified for recording. 4.0 volts D.C. at 100 m.p.h. and linear.	Electric Speed Indicator Co. . 12234 Triskett Road Cleveland, Ohio 44111
2. Wind direction transmitter F420-C-2, modified for recording on twin-channel recorder with 1400 ohms internal resistance.	Do.
3. Power supply and circuitry for recording vane. 5.0 volts D.C. output.	Do.
4. Esterline Angus Model A602C twin-channel recorder. Portable case with No. 2 hand-wound spring chart drive, hour and minute feed. Scale 0-1 mil. each side.	Local Esterline Angus Distributor
5. Inkwells for 31010B Model No. 14616-2 red and green ink. Order 3 spares.	Local Esterline Angus Distributor
6. 24 Esterline charts No. 31010B, 1 1/2 inches per hour with scale 0-100 left side and 0-150 right side.	Do.

B. CONTACT SYSTEM

1. Totalizing anemometer, Belfort Catalog No. 5-349A. 24 volts D.C. Max. 0.5 amp. One mile and 1/60 mile contacts.	Belfort Instrument Co. 4 North Central Avenue Baltimore, Maryland 21202
2. Wind direction transmitter (less vane) with universal bearing. Belfort Catalog No. 5-363. U.S. Weather Bureau Spec. No. 450.6112. 8 contacts. Max 3 amp. at 25 volts D.C.	Do.
3. Pintle for mounting anemometer	Do.
4. Electric speed indicator **spread-tail vane** - W.D.V.-400-1C. U.S. Weather Bureau Ser. No. S/N F012. Fits Belfort assembly.	Electric Speed Indicator Co. 12234 Triskett Road Cleveland, Ohio 44111
5. Power supply specs. for anemometer and vane: Regulated, variable 0-24 volts D.C. and 0-6 amps. output.	Check local electronics outlet
6. Esterline Angus Model A602X Operations 10-pen event recorder. Portable case with No. 2 hand-wound spring chart drive. Common return with 6 or 12 volt D.C. pen elements (specify one).	Local Esterline Angus Distributor
7. One pint red ink. Prt. No. 61101-R	Do.
8. 24 Esterline charts No. 1710-C, 3 inches per hour.	Do.
9. Cable. 6 copper strands minimum, shielded. Strand size No. 14-19 AWG.	Local Electrical Supplier or NI cond. surplus.
10. Ohm meter (for troubleshooting wind systems). Triplett Volt-ohm-milliammeter Model 310. L. B. Walker Radio Co. Cat. No. 3018	L. B. Walker Radio Co. 300 Bryant St. Denver, Colorado 80202

NOTE: Spare anemometers and vanes are essential.

II. PRECIPITATION

Item	Source
1. Recording rain and snow gage Belfort Cat. No. 5-780 with 12-inch dual traverse. LESS CHART DRIVE AND CYLINDER BUT WITH (100) 192 hour charts No. 5-4046B, complete with pen, ink, and dash pot fluid.	Belfort Instrument Co. 4 North Central Avenue Baltimore, Maryland 21202
2. Model 301D drum chart drive, battery actuated, 3.0 volts D.C. for recording rain and snow gage—drum height 6 5/8 inches. With power pack. **Gears for** 192 HOUR CHART.	Kingmann-White, Inc. P. O. Box G Placentia, Calif. 92670
3. Standard 8-inch can, 42 inches in length. Galvanized, painted a flat black.	Rex Industries 625 North 335 West Salt Lake City, Utah 84100
4. Support for 8-inch can, with angle iron legs.	Do.
5. Weather Bureau weighing scale. Detecto Mod. No. 0127-H-40, 2-revolution—40-pound capacity, circular dial with decal (reads directly in inches water for 8-inch can) without cover glass or sash. Adjustable tare pointers.	Environmental Science Services Administration. U. S. Weather Bureau, Executive Boulevard Bldg. 5, Room 627 Rockville, Maryland 20852 Atten: Mr. E. Lucas (AD 112)
6. Swiss snow kit (Schneewaage) 1 Federwaage Type Nr. 49lb 0-300 g Teilung 2 zu 2 g SET TARE AT ZERO. 1 Rohr 0.5 ltr. inhalt aus Aluminum 196 mm x 5? ??	Ernst Strohmeier Kreuzstrasse 52 Rapperswil SG SWITZERLAND

[11] *Trade and company names are used for the benefit of the reader, and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.*

III. TEMPERATURE

Item	Source
1 Townsend all metal thermometer support. Weksler Cat. No. 322A.	Weksler Instrument Corp. 195 East Merrick Road Freeport, New York 11520
2. Maximum thermometer. H. J. Green Cat. No. 101. Range -38° F. to 110° F. approx. One replacement max. therm. without backing.	Henry J. Green Instrument Co. 2500 Shames Drive Wespbury, New York
3. Minimum thermometer. H. J. Green Cat. No. 108—amber colored alcohol. Range -50° F. to +110° F. approx.	Do.
4. Hygrothermograph, vertical drum type, Belfort Cat. No. 5-594, LEST CHART DRIVE AND CYLINDER BUT WITH (100) 176 hour charts No. 5-209-WB. Complete with pen and ink.	Belfort Instrument Co. 4 North Central Avenue Baltimore, Maryland 21202
5. Model 301D Drum chart drive, battery actuated, 3.0 volts D. C. for hygrothermograph. Drum height 5 1/8 inches. With power pack. **Gears for 176 HOUR CHART.**	Kingmann-White Inc. P. O. Box G Placentia, Calif. 92670
6. Instrument shelter, medium size. U. S. Weather Bureau Spec. No. 450.0615. Cotton region type.	Science Associates 230 Nassau Street Box 230 Princeton, New Jersey 08540

IV. PRESSURE (ATMOSPHERIC)

1. Precision microbarograph, U.S.W.B. Spec. No. 450.7221. Chart ratio 2 1/2 to 1. Chart graduation in inches corrected to sea level. **Specify spot elevation of area where microbarograph will be operated.** Complete with pen, ink, and one set of charts No. 5-1071X weekly. Spring driven chart drive.	Belfort Instrument Co. 4 North Central Avenue Baltimore, Maryland 21202

V. TEST FIELD INSTRUMENTS

Item	Source
1. Ram penetrometer with 4 extension sections and 1- and 2-kg ram drivers.	Walter Buser Kleinmechanishe Werkstatte, Karstlernstrasse 5 Zurich, 43, SWITZERLAND
2. Triple beam balance. Ohaus model 750-S. (Keep at base station).	Contact local scientific supply house.
3. Stainless steel tube stock for making density tubes—304 WD stainless steel tubing, 2 3/8 inch O.D., .049 inch wall. Cut tubes 19.05 cm long and bevel one edge.	Contact local tubing distributor.
4. Plastic caps for 500 cm^3 tubes.	Test Lab. Corporation 216 N. Clinton Street Chicago, Illinois 60606
5. Shear frame: 1.9 cm depth; 10.2 cm front width; 9.7 cm back width. Two bars at 1/3 and 2/3 of total length. (See fig. 11). Bottom edges beveled. Wall thickness about 0.3 mm.	Contact local sheet metal shop.
6. Chatillon Gauge-R Catalog 516-1000. Graduated in pounds and grams.	Contact local scientific supply house.
7. Dial thermometers for snow profiles. Weston Model No. 226. Range -100° C. to +40° C.	Weston Electric Instrument Corp. Newark, New Jersey
8. Snow shovel. D-handle aluminum with square blade. Model 4A Zephyr-weight.	Wood Shovel and Tool Co. Piqua, Ohio (Order through local hardware outlet).
9. Snow pit wall brush. For hard snow. Plastic whisk broom. For soft snow: 3-inch nylon paint brush.	Local hardware store.

V. TEST FIELD INSTRUMENTS

Item	Source
10. Folding metric carpenter's rule. 2 meters long.	Local drafting store.
11. Hand lens. Double pocket lens, 2X-4X-8X. K.E. No. 830360	Do.
12. Millimeter Reticle—1 mm. plastic 2 inch by 3 inch approx.	General Biological Supply House Chicago, Illinois

Agriculture --- CSU, Ft. Collins

Gardner, Noel C., and Judson, Arthur.
1970. Artillery control of avalanches along mountain highways. USDA Forest Serv. Res. Pap. RM-61, 26 p., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

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Key words: Avalanches, snow density, anemometers, meteorological instruments, roads.

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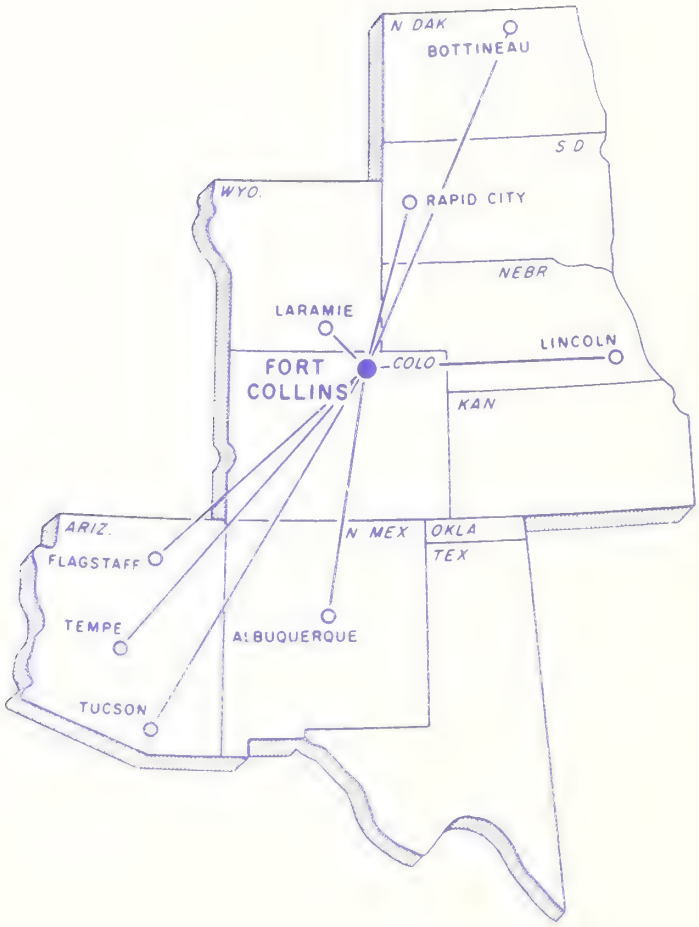
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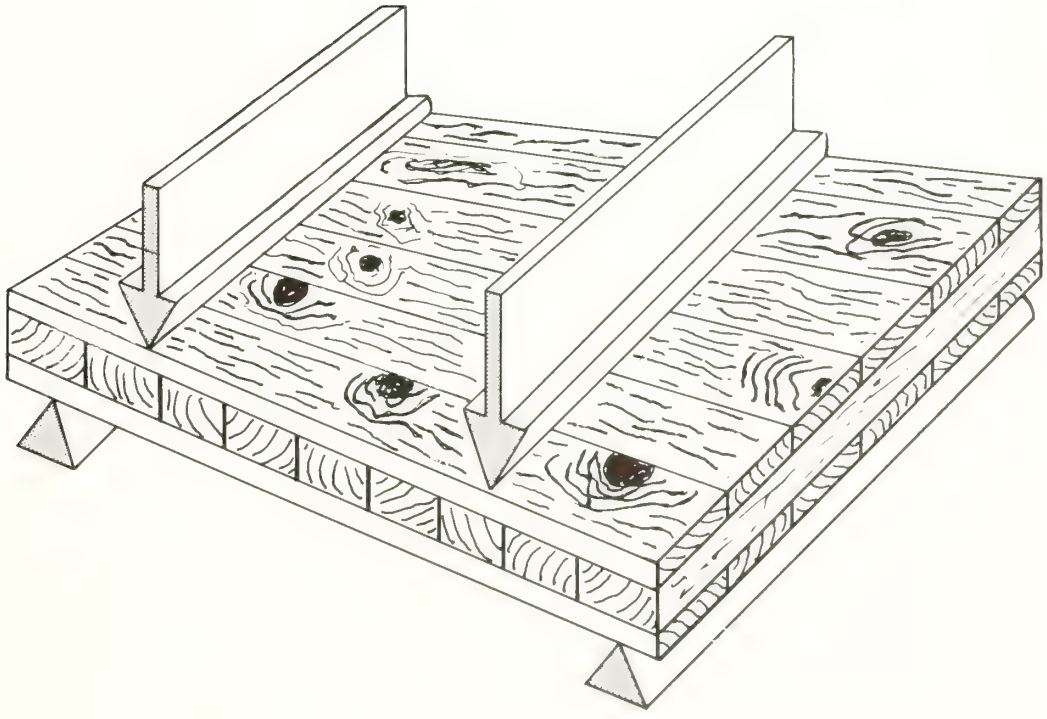

Rocky Mountain Forest and Range Experiment Station
U. S. Department of Agriculture Forest Service
Fort Collins, Colorado

USDA Forest Service
Research Paper RM-62

October 1970

Bending Strength of Panelized Decking from Black Hills Ponderosa Pine Lumber

by

Donald C. Markstrom

Associate Wood Technologist
Rocky Mountain Forest and Range Experiment Station[1]

and

Edwin H. Oshier

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South Dakota School of Mines and Technology
Rapid City, South Dakota

[1]Central headquarters maintained at Fort Collins in cooperation with Colorado State University.

ABSTRACT

Glued lumber decking panels fabricated with Grade 3 Common faces and 4 Common cores are as stiff or stiffer than conventional panelized decking designed for 4-foot spans. Only panels fabricated with Grade 1 and 2 Clear faces can be thinner or span a greater joist spacing than those with 3 Common faces and 4 Common cores.

Key Words: Panels, lumber, forest products, *Pinus ponderosa*.

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Acknowledgments

This study was conducted in cooperation with the South Dakota School of Mines and Technology, Rapid City, South Dakota, and through collaboration of the U. S. Forest Products Laboratory, Madison, Wisconsin.

Forest Products Laboratory scientists assisting were: Bruce G. Heebink, on original concept and design of the panel; M.L. Selbo, on fabrication technique; and Edward W. Kuenzi and Billy Bohannan, on engineering design and tests.

Bending Strength of Panelized Decking from Black Hills Ponderosa Pine Lumber

Donald C. Markstrom and Edwin H. Oshier

Introduction

Panelizing laminated decking shows considerable promise for utilizing low-grade lumber from ponderosa pine (Pinus ponderosa Laws.) and other species, and for recovering some of the lost sheathing market. This product can be designed for specific stiffness and strength requirements, can be manufactured into panel form for reduced installation costs, and could utilize large amounts of low-grade lumber. Lower grades of lumber, with lower moduli of elasticity and rupture, can be used as core material, with higher grades of lumber resawn for the outer plies (fig. 1).

Figure 1.--Test panel with resawed 4/4 lumber faces glued perpendicularly to the nominal 1-inch core boards.

The purpose of this study was to provide design information for laminated decking of Black Hills ponderosa pine lumber. The primary objective was to determine and compare both stiffness and ultimate load-carrying capacity of decking fabricated with different lumber grades.

It has been established that moisture content, density, knots, cross grain, shakes, checks, borer holes, wave, and decay affect the bending strength of wooden members.[2/] The most frequent and important strength-reducing defects in the lower common grades are knots. The modulus of rupture and modulus of elasticity are reduced by the lower compressive and tensile strength of the knot, associated cross grain, and by stress concentrations bordering the knot.

Methods

Fabricating the Panels

Rough air-dried 1- by 6-inch ponderosa pine boards, with defect types, sizes, and distributions representative of the lumber grades to be used in the test panels, were selected by a lumber grader at Black Hills sawmills. Forty test panels, 10 for each lumber face and core combination, were fabricated in the following combinations:

Faces	Cores
3 Common	4 Common
2 Common	4 Common
1 & 2 Clear	4 Common
1 & 2 Clear	1 & 2 Clear

[2] *Markwardt, L. J., and Wood, L. W. Simplified principles for structural grading of timber. USDA Forest Serv., Forest Products Lab. Rep. 2112, 19 p., illus. 1958.*

No decay or open defects greater than 1/16 inch in width were allowed in any member except those permitted on grade 4 Common. The moisture content of the rough 4/4 lumber, measured with an electric moisture meter on 10 randomly selected boards within each grade, averaged 11.5 percent and ranged from 10 to 13 percent. Stress distribution was sampled with three 1-inch sections sawed from three randomly selected boards within each lumber grade. The prong-type stress specimens indicated very little or no detectable stress within the sample boards.

The rough lumber for face boards was resawn with a vertical line bar resaw, jointed on one edge and ripped on the other edge to 5½-inch widths, and crosscut to 50-inch lengths (fig. 2). The rough lumber for core boards was planed on both faces to 25/32-inch thicknesses, jointed on one edge and ripped on the other edge to 5½-inch widths, and crosscut to 27½-inch lengths. Nine core boards and 10 face boards were randomly selected and arranged for each panel within each lumber face and core combination; upper and lower face boards were oriented at right angles to core boards. The five face boards were stapled together at the ends to facilitate handling and assure tight joints when pressed. The staples were removed when the laminated panel was trimmed to a 48-inch length.

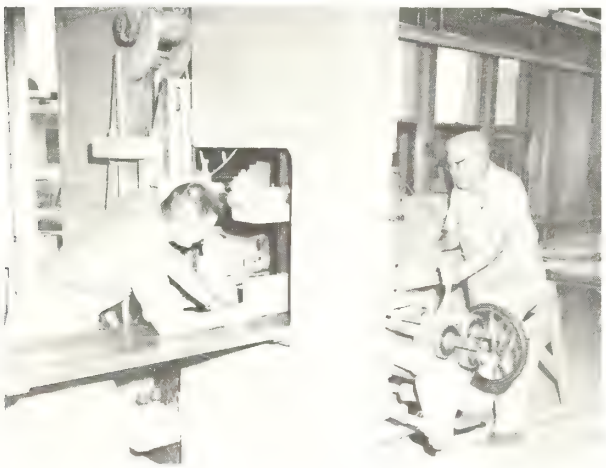

Figure 2.--Resawing rough 4/4 lumber into face boards. The saw was set to produce face boards with 7/16-inch thickness. This was necessary to provide for planing a smooth gluing surface, and having a final uniform thickness of 3/8 inch for all face boards.

Phenol-resorcinol adhesive was spread on both surfaces of the core boards at the rate of 65 to 70 pounds per thousand square feet. Glue was not spread on either the face boards or the edges of the core boards. The panels were pressed at 150 pounds per square inch (p.s.i.) for 6 hours at 80° to 90°F. (fig. 3). The cured panels were planed on both faces to a uniform thickness, and trimmed to a 24-inch width and 48-inch length. The panels were stickered and kept at a moisture content of 11 to 12 percent until tested for strength.

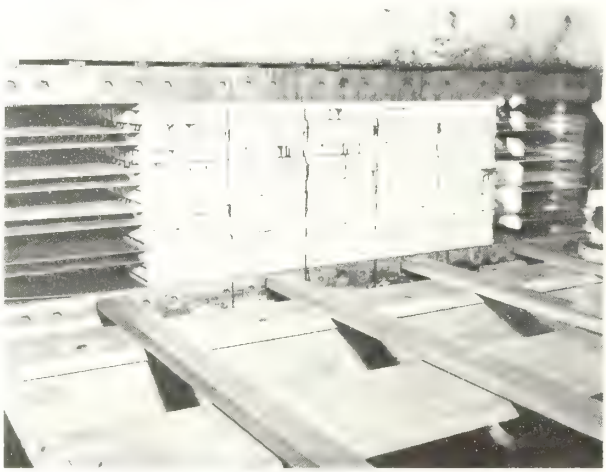

Figure 3.--Five panels were assembled and pressed at one time. Note squeeze out of glue.

Testing the Panels

The panels were statically bent over a 44-inch span with equal loads applied at quarter points (fig. 4). The movable head of the Tinius Olsen 400,000 pound Super L Testing Machine[3/] was driven at the rate of 0.34 inch per minute. A Tinius Olsen Model D-2 Deflectometer and Model 51 Recorder measured and recorded loads and corresponding midspan deflections between the supports. A tripoint deflectometer fabricated with plywood, three cap screws, and an Ames gage measured midspan deflection of the constant moment portion of the panel between the load points (fig. 5). A Bolex 16 mm. camera synchronized with a

[3] *Trade and company names are used for the benefit of the reader, and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.*

Sanborn 150 Recorder photographed the Ames gage every second.

The length, width, and thickness of the panels were measured within the ±0.3 percent accuracy stipulated by ASTM for tests of veneer, plywood, and other glued construction.[4/] Deflections were measured and recorded to the nearest 0.001 inch.

A 1-inch-wide section sawed across the width of the panel after testing was weighed to the nearest 0.01 gram, ovendried at 103°C., and reweighed to determine the moisture content.

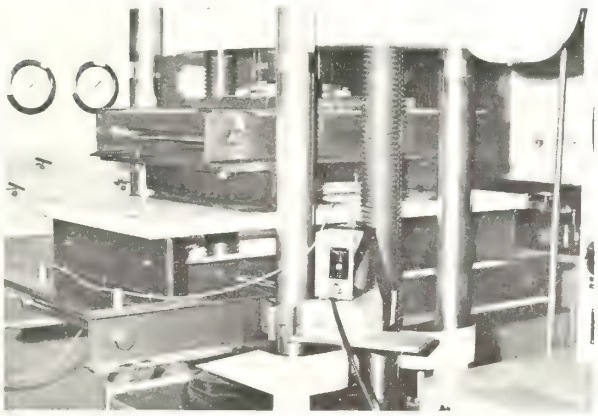

Figure 4.--Test panels were loaded at quarter points, and midspan deflection between supports was measured with a deflectometer. Two 1- by 25-inch stainless steel plates were placed between the panel and each loading edge of the static bending tool. Paraffin was spread between the plates to allow easy movement.

Results

Strength of Panels

Perhaps the most significant results were that the panels with grades 2 Common faces and a 4 Common core were neither significantly stronger nor stiffer than those with grades 3 Common faces and a 4 Common core (table 1). Also panels with grades 1 and 2 Clear faces and with a 1 and 2 Clear core, while stronger than those with a 4

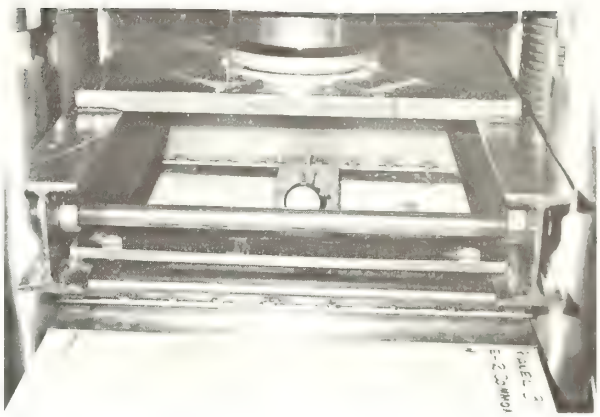

Figure 5.--Tripoint deflectometer located between load points to measure deflections for calculating modulus of elasticity, excluding shear.

Common core, were not significantly stiffer. As might be expected, the panels with grades 1 and 2 Clear faces and with either a 1 and 2 Clear or a 4 Common core were stronger and stiffer than those with either 2 or 3 Common faces and a 4 Common core. The between-panel variation of both strength and stiffness was greatest for the 3 Common face and 4 Common core combination.

Table 1.--Strength and stiffness of panels with different lumber grades in the faces and cores[1/]

Lumber grade		Modulus of rupture[2/]	Modulus of elasticity[1/]	
Faces	Cores		Including shear	Excluding shear
		p.s.i.	10⁶ p.s.i.	
1&2 Clear	1&2 Clear	7150 ± 540a	1.45 ± 0.04a	1.61 ± 0.05a
1&2 Clear	4 Common	8100 ± 380	1.40 ± 0.04a	1.55 ± 0.06a
2 Common	4 Common	5790 ± 620a	1.25 ± 0.05b	1.38 ± 0.08b
3 Common	4 Common	5310 ± 810a	1.17 ± 0.07b	1.33 ± 0.10b

[1/] Grade combinations with same letter are same--(5 percent) Duncan's multiple range test.

[2/] 95 percent confidence limit.

The average and range of certain test variables are shown in table 2. The height and width values are each averaged from six measurements within the constant moment portion of each beam. The average specific gravity based on total panel weight and volume for all panels was 0.46, greater than

[4] American Society for Testing and Materials. Standard methods of testing veneer, plywood, and other glued veneer constructions, ASTM Designation: D 805-63, p. 218-221. In 1966 Book of ASTM Standards, Part 16, Structural Sandwich Constructions; Wood; Adhesives. Philadelphia, Pa.: Amer. Soc. Test. Mater. 1966.

Table 2.--Average and range of measured or calculated variables for four tests of panel construction

Construction of test panels	Measured or calculated variables						
	Thickness	Width	Moisture content (ovendry weight)	Specific gravity	Stiffness		Ultimate load
					Including shear strain $(EI)_1$	Excluding shear strain $(EI)_2$	
	Inches	Inches	Percent		(Lb.-inch^2/inches of width)$\times 10^3$		Pounds
Faces--1&2 Clear Core --1&2 Clear							
Average	1.441	24.02	10.4	0.47	307	340	11,700
Range	1.433 to 1.445	24.00 to 24.03	9.5 to 11.2	0.45 to 0.48	287 to 336	312 to 371	10,000 to 13,100
Faces 1&2 Clear Core --4 Common							
Average	1.442	24.02	10.9	0.46	297	329	10,400
Range	1.400 to 1.443	24.00 to 24.03	10.2 to 11.4	0.44 to 0.47	278 to 317	299 to 357	9,350 to 11,800
Faces--2 Common Core --4 Common							
Average	1.439	24.01	11.3	0.44	262	289	7,370
Range	1.436 to 1.441	23.98 to 24.02	10.9 to 11.6	0.44 to 0.45	237 to 291	241 to 305	6,300 to 10,000
Faces--3 Common Core --4 Common							
Average	1.440	24.01	10.9	0.46	247	280	6,800
Range	1.437 to 1.441	23.98 to 24.03	10.4 to 11.4	0.44 to 0.48	218 to 287	241 to 323	5,130 to 9,800

the 0.41 value for ponderosa pine at 12 percent moisture content in the Wood Handbook.[5/]

Strength Formulas

The formulas to calculate stiffness and the moduli of elasticity and rupture are:

STIFFNESS:
Including shear strains—

$$(EI)_1 = \frac{P_1 A}{48\Delta_1}(3L_1^2 - 4A^2)$$

where

$(EI)_1$ = stiffness including shear strains, pounds-inch^2
P_1 = load within proportional limit of beam, pounds
A = distance from support to load point, inches
L_1 = span length between supports, inches
Δ_1 = deflection produced at midspan relative to supports by P_1, inches

Excluding shear strains—

$$(EI)_2 = \frac{P_2 AL_2^2}{16\Delta_2}$$

where

$(EI)_2$ = stiffness excluding shear strains, pounds-inch^2
P_2 = load within proportional limit of beam, pounds
A = distance from support to load point, inches
L_2 = span length within constant moment section over which deflection was measured, inches
Δ_2 = deflection produced at midspan of L_2 by load, P_2, inches

MODULUS OF ELASTICITY:
Including shear strains—

$$E_{f_1} = \frac{(EI)_1 - E_{c_1} \cdot I_c}{I_f}$$

where

E_{f_1} = modulus of elasticity of faces (parallel to grain), p.s.i.
I_f = moment of inertia of face plies, inches^4
E_{c_1} = modulus of elasticity of core (perpendicular to grain), assumed to be 0.05 E_{f_1}, p.s.i.
I_c = moment of inertia of core, inches^4
$(EI)_1$ = value from test data

[5/] *U. S. Forest Products Laboratory. Wood Handbook. U. S. Dep. Agr., Agr. Handb. 72, 528 p. 1955.*

Excluding shear strains—

$$E_{f_2} = \frac{(EI)_2 - E_{c_2} \cdot I_c}{I_f}$$

where

E_{f_2} = modulus of elasticity of faces (parallel to grain), p.s.i.
I_f = moment of inertia of face plies, inches^4
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MODULUS OF RUPTURE:

$$MOR = \frac{M_b \cdot C}{\left[\frac{T^3 - 0.454}{12}\right]W}$$

where

MOR = modulus of rupture
M_b = maximum bending moment, inch-pounds
C = distance from neutral axis to extreme fiber, inches
T = thickness of panel, inches
W = width of panel, inches

Most of the panels failed suddenly with no visible compression failure.

The load-deflection curves were linear to failure, which indicated sudden tension failure and little or no compression failure. Compression failure was apparent on only three of the panels.

Conclusions

An important conclusion from this study is that stiffness of panels fabricated with 3 Common faces and 4 Common cores is as high or higher than conventional panelized decking designed for 4-foot spans. The measured stiffness (EI) of the 10 test panels averaged 247,000 and ranged from 218,000 to 287,000 pounds-inch^2 per inch of width. The maximum bending moment of the 10 test panels averaged 1560 and ranged from 1170 to 2240 inch-pounds per inch of width.

A second conclusion is that only panels fabricated with grade 1 and 2 Clear faces can be thinner or span a greater joist spacing than those with 3 Common faces and 4 Common cores. Theoretically, the lumber grade of the faces, not that of the core, affects both stiffness and the maximum bending moment the most. The ratio of the moment of inertia of the face section to that of the core of a 1.441-inch-thick panel with a 0.781-inch core is calculated at 5.3:1.

This strength data will help a design engineer to determine working stresses when using this type of panel.

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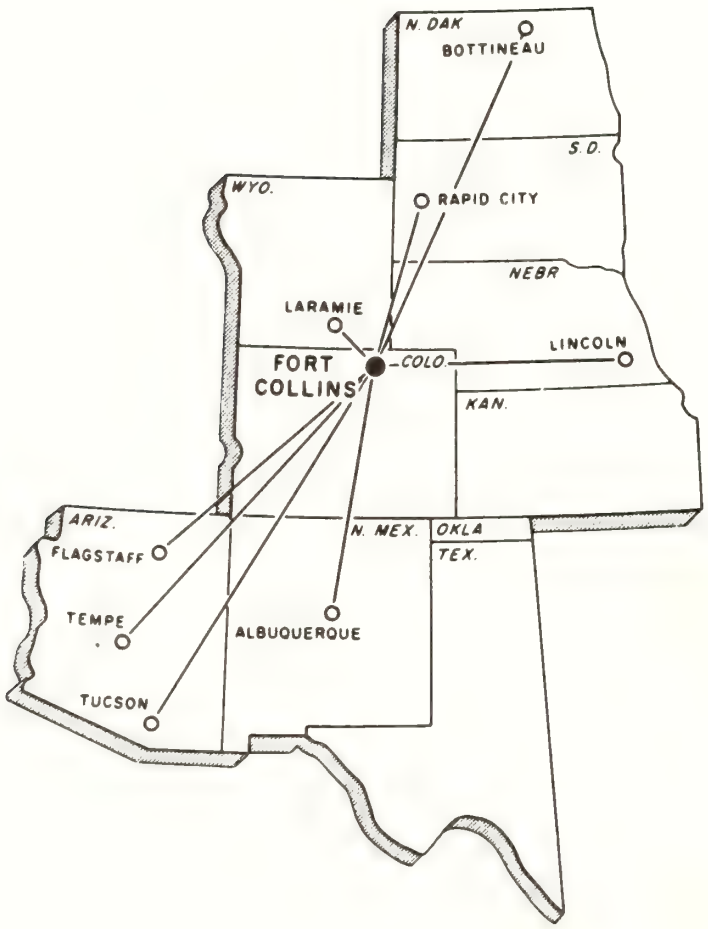
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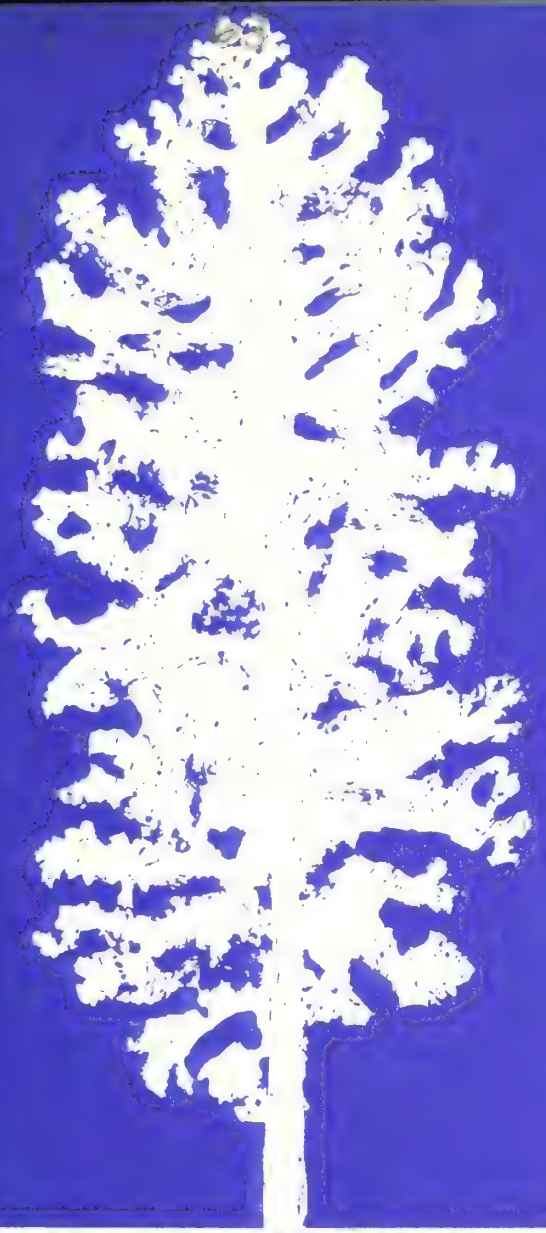
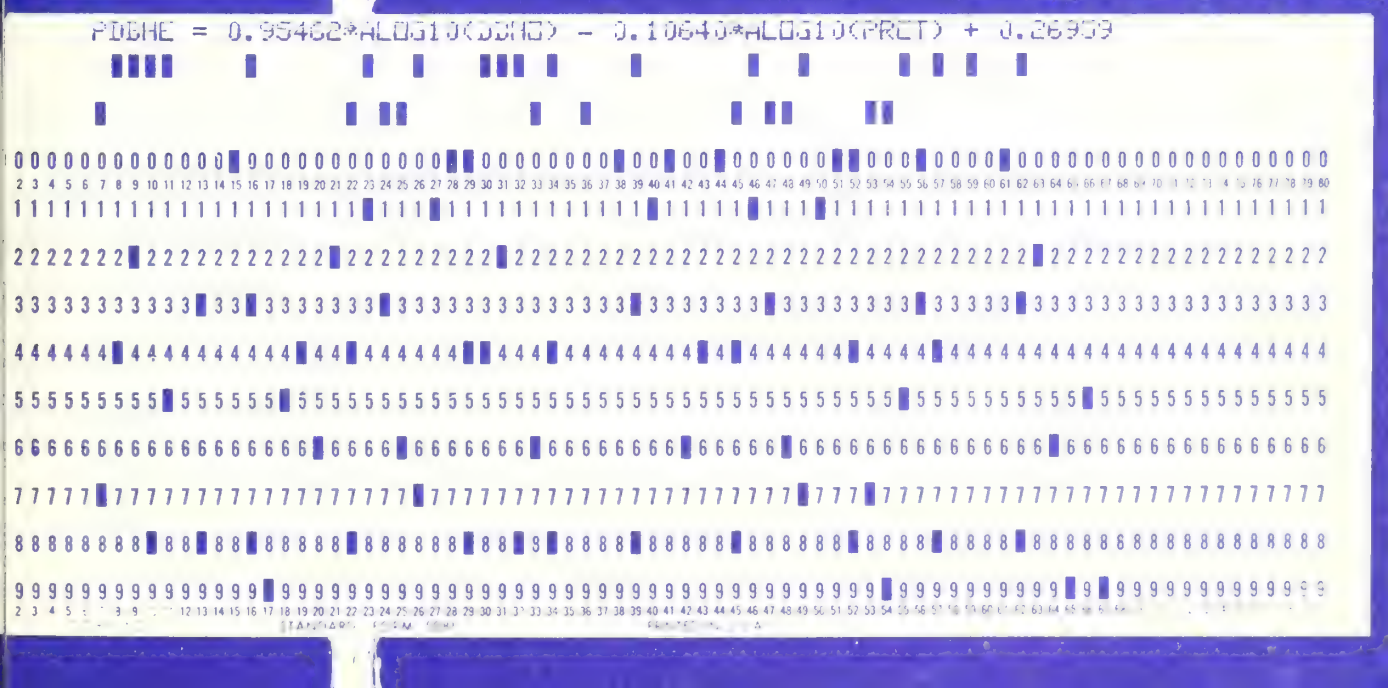


computer-assisted timber inventory analysis and management planning

by Clifford A. Myers

Rocky Mountain Forest and Range Experiment Station
U.S. Department of Agriculture
Forest Service



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Research Paper RM-63

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Computer-Assisted Timber Inventory Analysis and Management Planning

by

Clifford A. Myers, Principal Mensurationist

Rocky Mountain Forest and Range Experiment Station[1]

[1]Central headquarters maintained at Fort Collins, in cooperation with Colorado State University.

ABSTRACT

Presents computer programs, written in Fortran IV, for analysis of inventory data, computation of actual and optimum growing stocks and allowable cuts, and computation of other values needed for forest management planning. Computed volumes and areas are summarized in a timber management guide that replaces a conventional management plan. Effects of cultural operations and other changes are accounted for in computation of both actual and optimum conditions.

Key Words: Allowable cut, forest management, stand yield tables, timber management.

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Computer-Assisted Timber Inventory Analysis and Management Planning

Clifford A. Myers

INTRODUCTION

A forest operated as a business enterprise produces more than wood, forage, and other products. It is a prolific source of treatment and inventory records, reports, plans, maps, and other information. As with other businesses, there is great need for efficient information processing and retrieval so that all available information can be used for decisionmaking.

Procedures for analyzing inventory and other data and reducing them to summary values useful in planning, have been available for many years. These procedures have long provided information needed for management; their validity and usefulness usually have been widely accepted. There are, however, important deficiencies in the ways data have been handled and in the conventional methods of computation described in forest management texts. Specifically, the use of maps and overlays, timber atlas and similar records, and desk calculators involve such difficulties as the following:

1. There is usually more information available than can be stored, retrieved, and analyzed efficiently.
2. Maps, photographs, overlays, and tabulations of numerical data freeze the information at one or a few points in time. Changes in recorded information in response to changes in the forest are expensive and time consuming.
3. Higher offices may ask for information already assembled in whole or in part for a previous report, but for which the worksheets are no longer available. This can lead to much repetition in the assembly and analysis of data.
4. Information gathered for a specific purpose may be placed in a dead file after immediate needs are met. It may, however, have future value in management and decisionmaking, if it could be stored and relocated efficiently.
5. Timber management appears to proceed by steps, from management plan to management plan. Standing timber can and should be accounted for continuously, however, as is done for products entering and leaving a warehouse. There is danger of forgetting that a productive forest is a continuous, dynamic system.

High-speed computers with large memory capacity (both core and peripheral) provide a means of extracting efficiently large amounts of information from an accumulation of records. Data can be stored, retrieved, and updated with relative ease. Computations, if preplanned, can be done so cheaply that higher offices can obtain all the reports desired without disrupting the work schedule of local managers. There is no need to depend on plans that are expected to apply for several years despite fires, epidemics, and changes in economic conditions. A new plan, new maps, new cutting budget, and a new work schedule can be obtained as soon as recent changes in forest conditions can be recorded in the data file.

Program TEVAP (Timber, EValuation And Planning), described below and listed in Appendixes 1 and 3, provides a means of obtaining guidance quickly from a large volume of information. It is an example of the application of some information handling and analysis procedures to forest management. The program was developed around relationships that apply to timber production in even-aged stands because such relationships were available. It can, however, be expanded to include forage and other products and timber production in many-aged stands without change in the basic system.

Program TEVAP also provides an example of how a manager can obtain a management plan whenever he wants one. A computer run, using updated records, could be made each winter during the planning period between field or growing seasons. Large amounts of tedious computations and analyses are mechanized; management plans thus need not

be prepared only at intervals of perhaps 10 years. The term management plan refers to the quantitative section of a conventional timber management plan. This material, in the form produced by TEVAP, will hereafter be referred to as a management guide. Such information, regardless of how computed, is better considered as a guide or aid to management rather than as a plan. Following common modern practice, the transportation system and other general details can best be described in a report that covers the entire forest and all resources.

Programs such as TEVAP produce information that can be used for more purposes than control of current operations. They provide input data for programs that simulate operation of a forest under actual conditions. A manager can use the results of simulation to determine which one of several management alternatives will best meet his objectives (Chorafas 1965).

The program was written in USASI standard Fortran IV and tested on a CDC 6400[2] computer. Program organization permits modification for application to local tree species, procedures, and computing equipment. Improved or additional data and procedures can be inserted as they become available. Relationships that are specific to a species or location are described in Appendix 4. They can be replaced by statements applicable to other species or forest regions.

DATA HANDLING AND MANAGEMENT

Forest resource records are assembled from several sources. For timber, these sources are: (1) periodic forest inventory, (2) job reports prepared at the completion of each thinning, planting, sale, or other cultural operation, (3) area descriptions written after each fire or other catastrophe, and (4) stand and compartment analyses made as funds become available. Results of periodic inventories appear in management plans prepared after each inventory. Job reports and other data may be posted on the maps and tables of a timber atlas and summarized in annual reports. Although procedures vary among forest regions and classes of ownership, almost every item of information is used at some step in management and decision-making. Several operational computer programs for the analysis of periodic inventories illustrate how well the development of computation procedures has progressed.

It is unusual, however, for every item of information to be used for all appropriate purposes. For example, an individual fire report becomes part of the annual report on losses and suppression costs. It may then go to the protection file rather than be processed as an important item of inventory data.

There are valid reasons why the maximum amount of information may not be extracted from each item of data. Problems related to storage and retrieval are frequently of great importance. These include the size of record files, problems of assembling the data for use, and reassignment of people who know what has been recorded and where to find it. A forest manager is faced with other information problems that are less easily solved. There is little value in pooling records unless they can be updated to put them on a common time base. Also, data sufficient for a particular purpose may not be complete enough for more general use. A report on a thinning job may not contain sufficient stand or site data to permit its use in growth projections.

Procedures used in TEVAP to bypass some of the problems mentioned above are based on availability of a file of inventory records that can be updated as needed. This file contains stand data from many sources such as land books, job reports, and inventories. Stand descriptions prepared soon after thinning, fire suppression, and other activities provide excellent up-to-date inventory data and are used as such. Conventional inventories sample parts of a forest not already described in other records.

Inventory records for TEVAP, card type 16 in the list of data cards, are summaries of work reports or of conventional inventory records. They contain only the specific items needed for program execution. Overstory and understory components of a stand are described separately, if both are present. Computations can thus be made for stands being regenerated by shelterwood or seed tree systems. Growth can also be estimated for the many uneven-aged stands that may be described mathematically as two stands, overstory and understory.

Data used by TEVAP can be updated by computer once the basic relationships needed have been determined. How this may be done for the inventory records is explained in Appendix 5.

[2] *Trade names and company names are used for the benefit of the reader, and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.*

DESCRIPTION OF PROGRAM TEVAP

Program TEVAP consists of a main program and nine subroutine subprograms (Appendix 1, Appendix 3). Three subroutines (MAPS, AREA1, AREA2) provide alternative ways of computing areas, and only one of them is used at a time. Program execution thus requires use of the main program and seven subroutines.

Content and purpose of each routine are described in the sections that follow. Variable names are defined with the main program in Appendix 1 and in the list of contents of the data deck. The list of data cards also reports the number of cards needed and the sequence in which they are read. An example of an application of TEVAP, reported in Appendix 2, provides additional explanation of the program.

The number of possible units of each kind of forest subdivision is limited by the dimensions assigned appropriate variables in COMMON and DIMENSION statements. Each subdivision has a different limit so dimensions and loops that pertain to it can be identified. Restrictions to be observed unless appropriate changes are made are as follows:

1. The working circle may be subdivided into one to five blocks. A block may be an isolated unit of the working circle or one or more ranger districts. There must be at least one block in the working circle for proper program execution.
2. A maximum of three working groups may be defined without changes in dimensions. For brevity, formats of output tables provide for only two working groups. A working group consists of stands of the same forest type and managed under the same silvicultural system (Chapman 1950).
3. Provision is made for 20 vegetative or use types; 17 types are used for the example presented in Appendix 2. They are as follows:
   Types 1-5 - Five broad age classes within a pine working group that is regenerated by shelterwood.
   Types 6-10 - Five broad age classes within a spruce working group that is regenerated by small clearcuts.
   Type 11 - Deforested areas covered by brush.
   Type 12 - Deforested areas covered by grass.
   Type 13 - Recreation areas not included in computations of allowable cut.
   Type 14 - Rock outcrops and other areas where plant products cannot be produced.
   Type 15 - Areas covered by brush that will not be converted to forest.
   Type 16 - Areas with grasses and other herbaceous species that will be managed for forage production.
   Type 17 - Areas of other ownership within the boundaries of the working circle.
4. Stand ages may be grouped into 15 or fewer 10-year age classes. This classification is in addition to, but correlated with, the use of age in the forest type definitions.
5. Provision is made for up to 30 subcompartments per compartment. This specification need be considered only if subroutine MAPS is chosen as the source of area data.

Main Program

The main program calls five subroutines to execute five groups of operations in the following order:

1. Read values of control variables.
2. Compute area totals and subtotals.
3. Compute present and future volumes, periodic yields, and other descriptive values.
4. Compute optimum growing stocks and yields.
5. Summarize computations and print a guide to management.

TEVAP provides three alternatives for the second set of operations, computation of areas. One alternative (MAPS) requires complete forest subdivision plus compartment maps on punched cards or magnetic tape. Another (AREA2) requires only a knowledge of total area of the working circle and of each nontimber vegetative or use type. The third alternative (AREA1) represents one intermediate possibility, knowledge of type areas by compartments but with subcompartments not designated or mapped. A new routine may replace the three examples if still another level of information is of interest.

Each subroutine called by the main program writes one or more pages. Each page is identified by a type number such as "page type 3." Each type number, except type 5, designates a specific page layout. Pages are not numbered consecutively because page requirements will vary with size of the working circle and area alternative used. The last three items printed are designated types 1, 2, and 3 since many managers prefer that summary pages be the initial pages of a plan. Pages of

Z-fold paper can be separated and placed in proper numerical order. Temporary storage on scratch tapes can be used to reorder pages for output onto film.

Subroutine BASIS

BASIS enters into computer memory values of control variables that do not change during program execution. Some variables quantify management decisions and economic limitations. These include frequency and intensity of thinning, rotation lengths, volume of seed trees or shelterwood, and minimum volumes for commercial operations. Other variables define such items as expected growth of an overstory seed source and length of the delay between regeneration cutting and establishment of the new stand. Values of the control variables can be obtained from analysis of past records, measurements on temporary plots, and from computer simulations based on goals and policy (Myers 1968).

Values read by BASIS are printed as page type 4 to provide a record of the control variables. These variables are listed and defined in the description of the data deck.

Subroutine MAPS

Subroutine MAPS is one of three alternative routines used to compute areas. Complete forest subdivision to the subcompartment and compartment maps that show types and subcompartments are needed. The sequence of operations is explained by COMMENT statements in the program listing (Appendix 3).

Program MAPS accepts map data in the form of arrays of map codes on punch cards or tape. The form of input is specified by assignment of logical unit 3 to the card reader or to a tape drive. Array sizes, related DIMENSION statements, the system of map codes, and the area represented by one square of the map grid may be changed as desired.

Coding of types (KTYP) and subcompartments (KSUB) followed a procedure used for demographic and other studies. In the example, each section of 640 acres on a forest stand map was subdivided into 144 small squares. Each square of 4.444 acres (map 4 inches to 1 mile) was then assigned the code number of the predominant type. Portions of sections were combined to reproduce the entire compartment. Subcompartments were then designated and coded on the basis of type codes and field data. In the forest used as an example, all compartments fit into squares three sections on a side and could be represented by arrays of 36x36 2-digit code numbers. One west-to-east row of coding occupied the first 72 columns of a punch card. As many cards as necessary, but not more than 36, were punched to complete a type or subcompartment map for a compartment. All cards were run through an editing program to locate errors. This included a check that each subcompartment contained only one type. Corrected maps and control variables were then recorded on magnetic tape, using WRITE statements equivalent to the last three READ statements of MAPS.

The mapping procedure used is intended to illustrate the types of information needed and what can be done with it. In actual applications, more efficient procedures may be available. Hand-coding, for example, can be replaced by use of equipment that reduces map areas to digitized form. Forest managers can obtain procedural guides from the many applications of computer graphics to studies of urban problems and land use (Shahar 1970).

MAPS contains the one machine-dependent operation in program TEVAP. Map code numerals are converted to display code so blank areas of the maps will not be filled with minus zeros. Converted numbers are then printed with R format. Program statements must be modified if available equipment uses a different display code than the CDC 6400 used to test the program.

Two pages, types 5 and 6, are printed by MAPS. The form of page type 5 is optional, and is specified by the value read initially for the variable MAP (Appendix 3). Type and subcompartment maps and related area totals may be printed, if desired. Two pages are produced per compartment, one with the type map and one with the subcompartment map. Alternatively, only type and subcompartment areas may be printed (MAP = 0). Page type 6 reports block and working circle totals, and has the same format as the equivalent page produced by AREA1 and AREA2 (Appendix 2).

Following usual rules for forest subdivision, type and subcompartment boundaries are continually subject to change (Chapman 1950). The map file must therefore be updated prior to each computer run with subroutine MAPS. Cultural operations, growth into the next age class, and fire or other catastrophe create need for recoding.

Subroutine AREA1

Subroutine AREA1 is another of the three alternative routines that compute areas. It is used if compartments have been established and if type areas within compartments are known. It is assumed that either subcompartments have not been established, or that compartment maps are not available. AREA1 illustrates one possible situation in the range of degrees of administrative complexity between the limits served by MAPS and AREA2.

Type areas by compartment—inputs to the subroutine—are summed to obtain total acres by working group, by block, and by various other classifications and combinations thereof. These sums are passed through COMMON to GOT. COMMENT statements in the program listing, Appendix 3, explain the operations involved.

AREA1 prints type areas of each compartment on one form of type 5 pages (Appendix 3) and prints a type 6 page to report block, working group, and working circle totals. The type 6 page is the same as that produced by MAPS and AREA2.

Subroutine AREA2

Subroutine AREA2 is the third of the routines used to compute areas (Appendix 1). It is used if compartments have not been established, or if type areas within compartments are not known. This is the situation assumed for the example in Appendix 2. Type areas are computed from total production area, including nonstocked, and inventory information on type 16 data cards. Areas of nonforest types and of unregulated stands in recreation areas are subtracted from working circle area to get the area available for timber management. Stands of known area are assigned to the appropriate type. Remainder of the production area is allocated to forest types in proportion to the number of inventory records from each type. These inventory records are the same records used by subroutine GOT.

Type, working group, and block areas are recorded on pages type 5 and 6 (Appendix 2).

Subroutine GOT

Subroutine GOT processes the set of inventory records (data card type 16) to obtain present and future volumes and other values. Controls described in the following paragraphs apply to all computations.

Inventory records have a number in the ACRE field if the tree and site index values are amounts per acre averaged over a specific stand. The ACRE field has a blank or zero if the record is for a sample plot that describes a portion of the "unknown" forest area. In terms of recent National Forest inventories, the working circle may be at stage one (sampling the working circle), at stage two (compartment analysis), or with parts of the area at each level.

Records are counted by several classifications if the ACRE field is blank or has zeros. Nonzero values of ACRE are added to appropriate area totals and are subtracted from a duplicate array of the type areas computed by MAPS, AREA1, or AREA2. Type areas remaining in the duplicate array after all records are processed are assigned to age and site index classes in proportion to the number of zero-area records in each class.

Volume computations are bypassed for records from: (1) deforested areas, (2) areas below minimum site index for management, (3) trees too young or too small to have more than a few merchantable cubic feet per acre, and (4) stands below minimum age for inclusion in growing stock totals. With these exceptions, operations performed on individual inventory records produce the following values:

1. Present basal areas and volumes per acre.
2. Basal areas and volumes at the end of the planning period.
3. Growth expected during the next planning period, in cubic feet and board feet. Thinnings are computed as though done at the beginning and end of the period, and average growth is determined. It is assumed that about equal areas will be thinned each year of the period.
4. Potential yields during the next planning period if all areas are treated as specified by WORK on the inventory records. Half the potential growth of stands to be cut during the period is added to potential yields. Volumes are not included in total yields if they are less than the minimum commercial cuts specified by values of variables COMBF(I) and COMCU.

Two variables define time periods. TIME is the number of years in a planning period. It is the period considered in assigning the WORK index that identifies stands in need of treatment in the

near future. Possible values of WORK are defined in Appendix 1. RINT is the number of years for which the equations predict future d.b.h., height, and stand density. TIME must be equal to or a multiple of RINT.

Two sets of volume totals are maintained for block, age, and other subdivisions until all inventory records are processed. One set reports volumes of stands of known area. Volumes per acre are multiplied by area to obtain stand volumes for addition to the totals. The second set reports volumes from records with no entry for area in the ACRE field. Volumes per acre are summed for each subdivision specified in the program. These sums are converted to totals for each subdivision after all records have been processed and the area represented by one sample plot determined.

Summaries of area and present volumes are printed on pages type 7, 8, and 9. Working circle totals are subdivided among block, type, and site index classes. Many computed values are not reported at this point in the program, but are retained in COMMON for use by GOAL and GUIDE.

Inventory records used by AREA2 and GOT could be listed according to value of the WORK variable. This would provide information on where stands to be treated during the next management period are located. Such a list is not made by TEVAP, but could be produced by a separate run of the inventory records.

Subroutine GOAL

Subroutine GOAL computes the optimum conditions that would exist if all stands were thinned on schedule to the specified level, and if a balanced series of age classes had been established. Values needed to make these computations come from other routines. Management decisions based on experience, results of simulations, and statements of policy are entered by BASIS. Acres in each site index class of each working group are computed by GOT from area data and the inventory file.

Most computations are executed once for each site index class of each working group. Major operations, in the order performed for a site class, are as follows:

1. A yield table that incorporates management decisions such as frequency and intensity of thinning is printed as page type 10. Prediction equations used are described in Appendix 4. Thinnings and conversion of cubic feet to other units are simulated by subroutines CUTS and VOLS, described below. A yield table for a site class of a working group serves as a "normal" or standard for stands of that classification. It represents the goal toward which operations are directed. It is possible to produce many yield tables for a site class, which emphasizes that there cannot be a single table for managed stands of a species and site class. The term "managed" indicates that there are additional variables to be considered; one table cannot account for all the possibilities. Each table is useful only where goals and management decisions are as specified for its computation.

   Details of field work and computations needed to produce yield tables have been published elsewhere (Myers 1966, Myers and Godsey 1968). Much of GOAL from statement 45 to statement 184 is a duplication of procedures developed for yield table construction. Recent changes and generalizations are described in Appendix 4.
2. Volumes per acre at each year of stand age are obtained by interpolation between yield table values. These volumes, in board feet and cubic feet, are later summed to obtain optimum growing stocks. Results of the interpolations are printed as page type 11 to preserve them for possible use after the management guide has been produced.
3. Mean annual increment at rotation age is computed for each site class of each working group. If appropriate, tree felling ages do not equal rotation ages, but include the effects of delays in obtaining regeneration and the period seed trees or a shelterwood may be left over the new crop. Mean annual increments computed from yield table volumes are later used as "normal" increments in application of Heyer's formula:

$$E = WZ + \frac{WV - NV}{a}$$

   where: WZ is mean annual increment, WV is actual growing stock, NV is normal growing stock, and a is the adjustment period (Burger 1920).
4. GOAL calculates the number of acres and the growing stock in each age class with a balanced series of age classes. Area regulation is assumed for these computations; ANCUT(I,J) is area divided by rotation age. Acres with stands of zero age

are listed as such if delays in regeneration are expected with clearcut systems. Volumes of seed trees or shelterwood are included in age class totals if these silvicultural systems are used. Overwood volumes appear in the age class of the overwood trees during periods of delay in regeneration. Overwood volumes are in the youngest age classes after the new crop appears and before the overwood is removed. Tables on pages type 12 of Appendix 2 show examples of working groups managed by shelterwood and clearcut systems.

5. Annual cuts that might be obtained with a balanced series of age classes and optimum stand density are computed for each working group. Volumes from intermediate, regeneration, and final cuts are not combined into working group totals until GUIDE is called.

Subroutine GUIDE

Subroutine GUIDE computes several variables used in regulation of the cut, and prints three types of summary pages. Differences between actual and optimum growing stocks are computed and printed as part of page type 2. Acres and the volumes that could be obtained by thinning, regeneration cutting, and other operations during the next management period are summarized. Summary values, by block and type, are printed as page type 3. Separate pages of types 2 and 3 are printed for each working group.

Page type 1 contains a summary of computations made by the entire program, including a statement of the allowable cuts computed by GUIDE. As programed, page type 1 contains only a few of the items that could be assembled on summary pages. It is an example of what can be done, not an attempt to provide a standardized format.

TEVAP computes and reports three annual cuts, as examples of what can be done by this or similar programs. The types of cut are:

1. Idealized cut based on area regulation and a balanced series of age classes. Components of this cut are computed by GOAL and summarized by GUIDE.
2. Potential cut if all operations called for by the WORK index were performed, without regard to other restrictions. Periodic cuts are computed by GOT and converted to annual volumes by GUIDE.
3. Annual cut computed with a modification of Heyer's formula and an adjustment period of ADJ(I) years. Growing stock volumes computed from mean annual increment, as called for by the formula (Burger 1920), are not used. Instead, actual and desired growing stocks computed by GOT and GOAL are used by GUIDE to compute the desired values. Initial term of the formula is mean annual increment obtained from the idealized yield tables produced by GOAL.

Convenient comparisons of annual cuts provided by page type 1 suggest another use of programs such as TEVAP. They can be used as tools for research on the principles of allowable cut determination. For example, quite dissimilar results would be produced by various modifications of the Heyer formula. Periodic annual increments, PAIBD(I) and PAICU(I), are computed by GOT for use in such comparisons. Predominance of young stands in the forest described in Appendix 2 suggests that a relatively low annual cut, one computed from mean annual increment, be accepted as a guide to management (Dwight 1965).

Subroutine VOLS

VOLS is called by GOT and GOAL to convert total cubic feet per acre to other units. As listed in Appendix 1 and described in Appendix 4, conversions can be made to cubic feet to a 4-inch top and to board feet Scribner Rule. Other conversions could be added, such as those based on tree contents in square feet of veneer or in pounds of wood (Myers 1960).

Conversion factors (FCTR and PROD) are computed from average stand diameter, and are passed through COMMON to the calling routine. They are computed for one species and for one or two stand conditions at a time. Stand conditions may be present and future stand, overstory and understory, or similar paired requirements. Calls of the subroutine by GOAL require that only one value of each conversion factor be computed for each CALL statement. Each CALL VOLS is preceded by specification of the number of values of each factor needed and by the average diameter to be used. Minimum average diameters are specified for each factor; variability is so great with small diameters that the results serve no useful purpose.

Subroutine CUTS

Subroutine CUTS estimates average stand diameter after thinning from below. Estimated diameter after thinning (DBHE) is computed from diameter before thinning and the percentage of trees to be retained (Appendix 4). Successive percentages are tested until d.b.h. after thinning, number of trees retained, and residual basal area agree with the growing stock goal specified by THIN(I) or DLEV(I). Each call by GOT or GOAL is preceded by a statement that specifies the thinning level (REST) to be used.

Growing stock levels specify the basal area to be left after thinning in relation to average stand diameter (Appendix 4). Definition of several levels provides for alternative thinning intensities. Each level is named by the basal area to be left when average diameter is 10.0 inches or larger. Residual basal area increases with stand diameter until the diameter reaches 10.0 inches. Thereafter, basal area remains constant for any one stocking level. Subroutine CUTS therefore has two iterative loops so a full range of diameters, with both variable and constant basal area, may be accommodated. Limiting d.b.h. for selection of loops is 10.0 inches minus the smallest change expected from usual thinning practice.

DATA DECK FOR TEVAP

Nineteen types of punch cards or card images, listed below, are used to enter initial values of variables into computer memory. In this section, the word "card" may refer either to a standard 80-column punch card or to a card image on magnetic tape. Records that can best be handled by tape are identified in the descriptions of the subroutines.

In the following list, type numbers with asterisks designate alternatives (types 8 to 15, inclusive). Only two to four of these types need appear in the data deck for a single run of the program. Basis for choice is the area subroutine (MAPS, AREA1, AREA2) selected for call by the main program. All cards with type numbers not followed by asterisks must be included in the data deck so READ statements will be executed properly. Data cards are read in order of type numbers except for choice among types 8 to 15, and repetition needed because of number of working groups and other forest subdivisions.

Card types 1 to 7, inclusive, are read by BASIS. Types 1, 3, 4, and 7 consist of one card each; type 2 consists of three cards. One card of type 5 and one card of type 6 must be provided for each working group. Cards are read in order of type number, with cards of type 5 completed before type 6 is started; type 6 is completed before type 7 is read.

Subroutine MAPS, if used, reads card types 8 to 11, inclusive. One card of type 8 is needed to enter values that apply to all compartments. A set of cards for one compartment consists of type 9 (one card), type 10 (up to 36 cards), and type 11 (up to 36 cards). These sets are read in the sequence 9, 10, 11, 9, 10, 11, etc. until the number of sets or compartments (NCMP) on card type 3 has been processed.

AREA1, if used, reads card types 12 and 13. A set of cards for one compartment consists of one card of type 12 and the two cards that make up type 13. Sets are read in the sequence 12, 13, 12, 13, etc. until the number of sets or compartments (NCMP) on card type 3 has been processed.

Subroutine AREA2, if used, reads card types 14 to 17 inclusive. First, one card of type 14 with one to five block areas is read. One card of type 15 is then read for each entry on card type 14. Cards of type 15 must be arranged in the order block 1, block 2, and so forth, up to the highest block number needed, to match the order in which block areas are punched on card type 14. All cards or card images of type 16 are read after reading of card type 15 is completed. This reading of type 16 is a preliminary count, and does not substitute in any way for the reading of the same data by subroutine GOT. Reading is terminated by a card of type 17 with a zero or very large value for IBK.

GOT reads card types 16 and 17. The number of cards or card images of type 16 is determined by the number of inventory plots measured and/or by the number of subcompartments for which inventory data are known. To avoid counting of inventory records prior to program execution, a record (type 17) with a zero or very large value for block number follows the type 16 records. This terminates processing of the inventory and moves control to another place in the program. Fields for KOMP, ISUB, and ACRE on an inventory record will be blank when complete forest subdivision does not exist or is not used for the record.

Remaining cards in the data deck, types 18 and 19, are read by subroutine GOAL. The sequence is: (1) all type 18 cards for the first working group, (2) a type 19 card, (3) all type 18 cards for the second working group, and (4) another type 19 card, etc., until NWGP working groups have been processed. Zero or very large values for AGEO (type 19) terminate each set of type 18, so preliminary knowledge of the number of site classes inventoried is not necessary.

Card type	Read by	No. of cards	Variable name	Columns	Format	Description of variable
1	BASIS	1	FORET(I)	1-24	3A8	Name of the forest or working circle.
2	BASIS	3	TYPNM(I)	1-80	8A10	Brief name for each vegetative or use type.
3	BASIS	1	NBK	1-4	I4	Number of blocks in working circle. Must be at least one.
			NCMP	5-8	I4	Number of compartments in working circle. Leave blank for AREA2.
			NWGP	9-12	I4	Number of working groups in working circle.
			MIN	13-16	I4	Minimum age for inclusion of stand volume in growing stock.
4	BASIS	1	ROTA	1-8	F8.3	Longest possible rotation to be shown in yield tables.
			CYCL	9-16	F8.3	Years between intermediate cuts.
			RINT	17-24	F8.3	Number of years for which the equations predict growth.
			COMCU	25-32	F8.3	Minimum commercial cut per acre, hundreds of cu. ft.
			BFMRCH	33-40	F8.3	Minimum M bd. ft. per acre for inclusion in growing stock.
			TIME	41-48	F8.3	Number of years in planning period.
5	BASIS	1 per working group	GROWB(I)	1-5	F5.3	Growth rate in percent of bd. ft. in shelterwood, working group I.
			GROWC(I)	6-10	F5.3	Growth rate in percent of cu. ft. in shelterwood, working group I.
			FINL(I)	11-14	F4.1	Years between regeneration cut and final removal of shelterwood, working group I.

Card type	Read by	No. of cards	Variable name	Columns	Format	Description of variable
			DLEV(I)	15-18	F4.1	Growing stock level for cuts after initial thinning, working group I.
			THIN(I)	19-22	F4.1	Growing stock level for initial thinning, working group I.
			POOR(I)	23-26	F4.1	Minimum site index to be managed for timber, working group I.
			SHELT(I)	27-30	F4.1	M bd. ft. to be left as shelterwood, working group I.
			SHWD(I)	31-34	F4.1	Hundreds of cu. ft. to be left as shelterwood, working group I.
			COMBF(I)	35-38	F4.1	Minimum commercial cut in M bd. ft. per acre, working group I.
			DELAY(I)	39-42	F4.1	Years between regeneration cut and regeneration, working group I.
			ADJ(I)	43-46	F4.1	Length of period of adjustment in allowable cut formula, working group I.
6	BASIS	1 per working group	RAGE(I,J)	1-40	10F4.0	Rotation selected for working group I and site index class J.
7	BASIS	1	DATE(I)	1-24	3A8	Date of most recent changes in data files.
8 *	MAPS	1	MAP	1-4	I4	Index to print (1) or to omit (0) compartment maps.
			SCALE	5-10	F6.4	Acres represented by one code number on a compartment map.
9 *	MAPS	1 per comp.	KBK	1-4	I4	Block in which the compartment is located.
			KOMP	5-8	I4	Number of the compartment being processed.
			NROW	9-12	I4	Number of rows of map symbols in the compartment map.

Card type	Read by	No. of cards	Variable name	Columns	Format	Description of variable
10 *	MAPS	NROW per comp.	KTYP(I,J)	1-72	36I2	Type numbers in compartment type map.
11 *	MAPS	NROW per comp.	KSUB(I,J)	1-72	36I2	Subcompartment numbers in map of subcompartments.
12 *	AREA1	1 per comp.	KBK	1-4	I4	Block in which the compartment is located.
			KOMP	5-8	I4	Number of the compartment being processed.
13 *	AREA1	2 per comp.	ARETY(I)	1-80	10F8.1	Acres of type I in the compartment being processed.
14 *	AREA2	1	ARBK(I)	1-40	5F8.1	Acres in block I.
15 *	AREA2	1 per block	SARETY(I,J)	1-64	8F8.1	Acres of nontimber type J in block I.
16	AREA2 GOT	1 per plot or subcomp.	IBK	1-2	I2	Block number. Must be at least 1 block in working circle.
			KOMP	3-6	I4	Compartment number. Enter only if applicable.
			ISUB	7-9	I3	Subcompartment number. Enter only if applicable.
			QTR1	10-12	A3	Location in ¼ ¼ of public land survey. Replace columns 10-26 with other location data, where appropriate.
			QTR2	13-15	A3	Location in ¼ section of public land survey.
			SECT	16-18	A3	Section in which inventory plot or largest part of compartment is located.
			TOWN	19-22	A4	Township location of the section.
			RANG	23-26	A4	Range location of the section.
			SITE	27-30	F4.0	Average site index of the plot or subcompartment.
			STRY	31-32	F2.0	Indicates whether type is based on overstory (blank) or on understory (1).

Card type	Read by	No. of cards	Variable name	Columns	Format	Description of variable
			NTYP	33-35	I3	Vegetative or use type of the plot or subcompartment.
			WORK	36-38	F3.0	Code number of treatment needed during planning period.
			DBH(1)	39-42	F4.1	Average d.b.h. of the overstory trees.
			HT(1)	43-45	F3.0	Average height of dominant and codominant overstory trees.
			DEN(1)	46-50	F5.0	Number of overstory trees per acre.
			AGE(1)	51-54	F4.0	Average age of overstory trees.
			DBH(2)	55-58	F4.1	Average d.b.h. of the understory trees.
			HT(2)	59-61	F3.0	Average height of potential dominants and codominants in the understory.
			DEN(2)	62-66	F5.0	Number of understory trees per acre.
			AGE(2)	67-70	F4.0	Average age of understory trees.
			ACRE	71-75	F5.1	Area of the subcompartment described. Leave blank if data refer to plot, not stand, data.
			WHEN	76-80	F5.0	Year of first growing season after inventory was made.
17	AREA2 GOT	1	(Very large or zero value of IBK in first 2 columns to stop reading of type 16 records.)			
18	GOAL	1 per site class in a working group	AGEO	1-5	F5.1	Initial age in yield table for the site class.
			DENO	6-10	F5.1	Number of trees per acre expected before thinning at age AGEO.
			DBHO	11-15	F5.1	Average stand d.b.h. at age AGEO with density DENO.
19	GOAL	1 per working group	(First 5 columns blank or with number larger than ROTA to clear cards of type 18.)			

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APPENDIX 1

Listing of Program TEVAP

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      PROGRAM TEVAP
     1(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE4=TAPE4,TAPE8=TAPE8)
C
C  SPECIFICATIONS OF VARIABLES.
C
C     AREA(I,J) = ACTUAL GROWING STOCK IN M BD. FT. FOR WORKING GROUP I
C          AND AGE CLASS J.
C     AREA(I) = DEFORESTED ACRES IN BLOCK I.
C     ARF(I,J,K) = ACRES TO RECEIVE FINAL CUT DURING NEXT PERIOD -
C          WORKING GROUP I, BLOCK J, AGE CLASS K.
C     ACINT(I) = ACRES RECEIVING INTERMEDIATE CUT ANNUALLY IN BALANCED
C          FOREST, WORKING GROUP I.
C     ACRE = AREA OF THE STAND DESCRIBED BY THE INVENTORY RECORD, IF
C          KNOWN. BLANK INDICATES RECORD APPLIES TO SAMPLE PLOT.
C     ACRGN(I,J,K) = ACRES TO RECEIVE REGENERATION CUT DURING NEXT
C          PERIOD - WORKING GROUP I, BLOCK J, AGE CLASS K.
C     ACS(I,J,K) = ACRES OF WORKING GROUP I, BLOCK J, SITE CLASS K.
C     ACSPE(I,J) = ACRES OF WORKING GROUP I IN BLOCK J.
C     ADJ(I) = YEARS IN ADJUSTMENT PERIOD, WORKING GROUP I.
C     AGE(I) = AVERAGE AGE OF OVERSTORY(I=1) OR UNDERSTORY(I=2).
C     AGF = INITIAL AGE IN YIELD TABLE.
C     ALLGF(I,J) = GROWING STOCK GOAL FOR WORKING GROUP I, SITE CLASS J.
C          CUBIC FEET OF ENTIRE STANDS TO ROTATION AGE.
C     ALLOWC(I) = ALLOWABLE ANNUAL CUT IN HUNDREDS OF CU. FT., BASED ON
C          ACTUAL AND DESIRED GROWING STOCKS OF WORKING GROUP I.
C     ALWBF(I) = ALLOWABLE ANNUAL CUT IN M BD. FT., BASED ON ACTUAL AND
C          DESIRED GROWING STOCKS OF WORKING GROUP I.
C     AMCA(I,J) = ACTUAL GROWING STOCK IN HUNDREDS OF CU. FT. FOR
C          WORKING GROUP I AND AGE CLASS J.
C     ANBDF(I) = M BD. FT. PER ACRE AT END OF EACH YEAR.
C     ANCMF(I,J) = AREA / ROTATION FOR WORKING GROUP I, SITE CLASS J.
C     ANCUVF(I) = CU. FT. STANDING PER ACRE AT END OF EACH YEAR.
C     ANNAC = TOTAL ACRES TO BE TREATED ANNUALLY DURING NEXT PERIOD.
C     ANNBD = EXPECTED TOTAL ANNUAL YIELD DURING NEXT PERIOD IN M BD. FT.
C     ANNCU = EXPECTED TOTAL ANNUAL YIELD DURING NEXT PERIOD IN CU. FT.
C     AREA(I) = AREA OF BLOCK I.
C     AREA(I,J) = AREA OF SITE CLASS J OCCUPIED BY WORKING GROUP I.
C          INCLUDES SHARE OF DEFORESTED AREA.
C     ARECP = TOTAL AREA OF COMPARTMENT.
C     ARESC(I) = ACRES IN SUBCOMPARTMENT I.
C     ARETY(I) = ACRES OF TYPE I IN ONE COMPARTMENT.
C     BARE = DEFORESTED ACRES IN A COMPARTMENT.
C     BARS(I,J) = DEFORESTED ACRES OF SITE J IN BLOCK I.
C     BAS(I) = BASAL AREA OF OVERSTORY(I=1) OR UNDERSTORY(I=2).
C     BASC = BASAL AREA REMOVED PER ACRE.
C     BASO = BASAL AREA PER ACRE BEFORE THINNING.
C     BAST = BASAL AREA PER ACRE AFTER THINNING.
C     BDAI = M.A.I. IN M BD. FT. FROM YIELD TABLE.
C     BDFC(I) = M BD. FT. REMOVED PER ACRE.
C     BDFO(I) = M BD. FT. PER ACRE BEFORE THINNING.
C     BDFT(I) = M BD. FT. PER ACRE AFTER THINNING.
C     BDMAI(I) = M.A.I. IN M BD. FT. FROM YIELD TABLE AND ACRES IN SITE
C          CLASS, WORKING GROUP I.
C     BFAGE(I,J) = GROWING STOCK GOAL IN M BD. FT. FOR WORKING GROUP I
C          AND AGE CLASS J.
C     BFBLK(I) = M BD. FT. IN BLOCK I.
C     BFINT(I) = M BD. FT. FROM INTERMEDIATE CUTS ANNUALLY IN BALANCED
C          FOREST, WORKING GROUP I.
C     BFM(I) = M BD. FT. IN OVERSTORY(I=1) OR IN UNDERSTORY(I=2).
C     BFMRCH = MINIMUM VOLUME TO BE INCLUDED IN BD. FT. GROWING STOCK.
C     BFS(I) = GROWING STOCK GOAL BY AGE CLASS I FOR ONE SITE CLASS OF
C          WORKING CIRCLE, M BD. FT.
C     BFSP(I,J) = M BD. FT. OF WORKING GROUP I IN BLOCK J.
C     BFTB(I,J) = M BD. FT. IN TYPE J OF BLOCK I.
C     BFTH(I,J) = CURRENT POTENTIAL PERIODIC YIELD FROM THINNINGS IN
C          BLOCK I AND TYPE J, M BD. FT.
C     BEVOL = M BD. FT. PER ACRE MINUS VOLUME LEFT AS SEED SOURCE.
C     CFAGE(I,J) = GROWING STOCK GOAL IN MERCHANTABLE CUBIC FEET FOR
C          WORKING GROUP I AND AGE CLASS J.
C     CFAI = M.A.I. IN HUNDREDS OF CU. FT. FROM YIELD TABLE.
C     CFBF(I,J) = GROWING STOCK GOAL FOR WORKING GROUP I, SITE CLASS J.
C          CUBIC FEET IN SAWLOG TREES.
C     CFMC(I) = MERCHANTABLE CU. FT. REMOVED PER ACRE.
C     CFMER(I) = MERCH. CU. FT. IN BLOCK I, IN HUNDREDS.
C     CFMO(I) = MERCHANTABLE CU. FT. PER ACRE BEFORE THINNING.
C     CFMT(I) = MERCHANTABLE CU. FT. PER ACRE AFTER THINNING.
C     CFTB(I,J) = TOTAL CU. FT. IN TYPE J OF BLOCK I, IN HUNDREDS.
C     CFVOL = CU. FT. PER ACRE MINUS VOLUME LEFT AS SEED SOURCE.
C     CM(I) = HUNDREDS OF MERCH. CU. FT. IN OVERSTORY(I=1) OR IN
C          UNDERSTORY(I=2).
C     CMS(I) = GROWING STOCK GOAL BY AGE CLASS I FOR ONE SITE CLASS OF
C          WORKING CIRCLE, HUNDREDS OF CU. FT.
C     CMSP(I,J) = MERCH. CU. FT. OF WORKING GROUP I IN BLOCK J.
C     CMTB(I,J) = HUNDREDS OF MERCH. CU. FT. IN TYPE J OF BLOCK I.
C     CMTH(I,J) = CURRENT POTENTIAL PERIODIC YIELD FROM THINNINGS IN
C          BLOCK I AND TYPE J, HUNDREDS OF CUBIC FEET.
C     COMBF(I) = MINIMUM COMMERCIAL CUT OF WORKING GROUP I IN M BD. FT.
C     COMCU = MINIMUM COMMERCIAL CUT IN CU. FT.
C     CUINT(I) = CU. FT. FROM INTERMEDIATE CUTS ANNUALLY IN BALANCED
C          FOREST, WORKING GROUP I.
C     CUMAI(I) = M.A.I. IN HUNDREDS OF CU. FT. FROM YIELD TABLE AND ACRES
C          IN SITE CLASS, WORKING GROUP I.
C     CUTA(I,J) = POTENTIAL BD. FT. VOLUME, LESS SHELTERWOOD, AVAILABLE
C          FROM REGENERATION CUTS - BLOCK I, TIMBER TYPE J.
C     CUTB(I,J) = POTENTIAL BD. FT. VOLUME AVAILABLE FROM REMOVAL OF
C          OVERWOOD - BLOCK I, TIMBER TYPE J.
C     CVR(I) = NUMBER OF MAP SQUARES IN TYPE I.
C     CYCL = INTERVAL BETWEEN INTERMEDIATE CUTS.
C     DATE = DATE OF MOST RECENT CHANGES IN INVENTORY OR OTHER DATA.
C     DBH(I) = AVERAGE D.B.H. OF OVERSTORY(I=1) OR UNDERSTORY(I=2).
C     DBHO = AVERAGE STAND D.B.H. BEFORE THINNING.
C     DBHT = AVERAGE STAND D.B.H. AFTER THINNING.
C     DELAY(I) = YEARS DELAY BETWEEN REGENERATION CUT AND ESTABLISHMENT
C          OF NEW STAND, WORKING GROUP I.
C     DEN(I) = TREES PER ACRE IN OVERSTORY(I=1) OR UNDERSTORY(I=2).
C     DENC = TREES REMOVED PER ACRE.
C     DENO = TREES PER ACRE BEFORE THINNING.
C     DENT = TREES PER ACRE AFTER THINNING.
C     DFBF(I,J) = DIFFERENCE BETWEEN ACTUAL STOCK AND GOAL IN M BD. FT.
C          FOR WORKING GROUP I AND AGE CLASS J.
C     DFMC(I,J) = DIFFERENCE BETWEEN ACTUAL STOCK AND GOAL IN HUNDREDS
C          OF CU. FT. FOR WORKING GROUP I AND AGE CLASS J.
C     DLEV(I) = GROWING STOCK LEVEL FOR THINNINGS AFTER INITIAL CUT,
C          WORKING GROUP I.
C     EQIV(I) = ACRES PER STANDARD ACRE, SITE CLASS I - FROM BOARD FEET.
C     EQVC(I) = ACRES PER STANDARD ACRE, SITE CLASS I - FROM CUBIC FEET.
C     FAC(I) = RATIO OF YIELD OF SITE CLASS I TO STANDARD YIELD, BOTH
C          IN BOARD FEET.
C     FACC(I) = RATIO OF YIELD OF SITE CLASS I TO STANDARD YIELD, BOTH
C          IN CUBIC FEET.
C     FBA(I) = FUTURE BASAL AREA OF OVERSTORY (1) OR UNDERSTORY (2).
C     FBF(I) = FUTURE M BD. FT. IN OVERSTORY (1) OR UNDERSTORY (2).
C     FCTR(I) = MERCHANTABLE CU. FT. PER TOTAL CU. FT. - FACTOR.
C     FDM(I) = FUTURE AVERAGE D.B.H. OF OVERSTORY(1) OR UNDERSTORY (2).
C     FEN(I) = FUTURE TREES PER ACRE IN OVERSTORY(1) OR UNDERSTORY (2).
C     FHT(I) = FUTURE AVE. HEIGHT OF OVERSTORY (1) OR UNDERSTORY (2).
C     FINB(I) = EXPECTED ANNUAL YIELD IN M BD. FT. FROM FINAL CUTS
C          DURING NEXT PERIOD, WORKING GROUP I.
C     FINC(I) = EXPECTED ANNUAL YIELD IN CU. FT. FROM FINAL CUTS DURING
C          NEXT PERIOD, WORKING GROUP I.
C     FINL(I) = YEARS BETWEEN REPRODUCTION CUT AND REMOVAL OF OVERWOOD,
C          WORKING GROUP I, INCLUDES DELAY(I), IF ANY.
C     FMC(I) = FUTURE MERCH. CU. FT. IN OVERSTORY (1) OR UNDERSTORY(2).
C     FNAC(I) = EXPECTED ACRES TO RECEIVE FINAL CUTS ANNUALLY DURING
C          NEXT PERIOD, WORKING GROUP I.
C     FNBD(I) = ANNUAL YIELD FROM FINAL CUTS WITH BALANCED SERIES OF AGE
C          CLASSES, M BD. FT. OF WORKING GROUP I.
C     FNCU(I) = ANNUAL YIELD FROM FINAL CUTS WITH BALANCED SERIES OF AGE
C          CLASSES, CU. FT. OF WORKING GROUP I.
C     FORET(I) = NAME OF FOREST OR WORKING CIRCLE.
C     FVL(I) = FUTURE TOTAL VOLUME OF OVERSTORY(1) OR UNDERSTORY (2).
C     GRBD(I,J,K) = PERIODIC GROWTH OF WORKING GROUP I, BLOCK J, AND AGE
C          CLASS K IN M BD. FT.
C     GRMC(I,J,K) = PERIODIC GROWTH OF WORKING GROUP I, BLOCK J, AND AGE
C          CLASS K IN HUNDREDS OF MERCH. CU. FT.
C     GROWB(I) = GROWTH RATE OF SHELTERWOOD, WORKING GROUP I, BD. FT. IN
C          PCT.
C     GROWC(I) = GROWTH RATE OF SHELTERWOOD, WORKING GROUP I, CU. FT. IN
C          PCT.
C     GRUP(I) = AREA OF WORKING GROUP I IN A COMPARTMENT.
C     GVLBF(I) = TOTAL GROWING STOCK GOAL FOR WORKING GROUP I, M BD. FT.
C     GVLCU(I) = TOTAL GROWING STOCK GOAL FOR WORKING GROUP I, CU. FT.
C          SUM OF APPROPRIATE SUBCF(I,J) FOR SUB-SAWLOG TREES.
C     HELP(I,J) = POTENTIAL NONCOMMERCIAL THINNING IN NEXT PERIOD, ACRES
C          OF TYPE J IN BLOCK I.
C     HT(I) = AVERAGE HEIGHT OF OVERSTORY(I=1) OR UNDERSTORY(I=2).
C     HTSO = TREE HEIGHT BEFORE THINNING.
C     HTST = TREE HEIGHT AFTER THINNING.
C     IBK = BLOCK SOURCE OF INVENTORY RECORD.
C     ISUB = SUBCOMPARTMENT SOURCE OF INVENTORY RECORD.
C     KBK = BLOCK NUMBER.
C     KCMP = COMPARTMENT NUMBER.
C     KSUB(I,J) = SUBCOMPARTMENT NUMBERS OF MAP SQUARES.
C     KTYP(I,J) = TYPE CLASSIFICATION OF MAP SQUARES.
C     MAP = INDEX TO PRINT (1) OR OMIT (0) MAPS.
C     MIN = MINIMUM AGE FOR STAND TO BE INCLUDED IN GROWING STOCK.
C     MNK = TEMPORARY VARIABLE, ASSIGNED MEANINGS AS NEEDED.
C     NBK = NUMBER OF BLOCKS IN WORKING CIRCLE. MUST BE AT LEAST ONE.
C     NCMP = NUMBER OF COMPARTMENTS IN WORKING CIRCLE.
C     NROW = NUMBER OF ROWS IN COMPARTMENT MAP.
C     NSBK(I) = NUMBER OF SUBCOMPARTMENTS IN BLOCK I.
C     NST(I) = NUMBER OF SITE CLASSES IN WORKING GROUP I.
C     NSUB = NUMBER OF SUBCOMPARTMENTS IN WORKING CIRCLE.
C     NTYP = COVER OR USE TYPE OF INVENTORY PLOT OR SUBCOMPARTMENT.
C     NWGP = NUMBER OF WORKING GROUPS IN WORKING CIRCLE.
C     OPBD(I) = ALLOWABLE ANNUAL CUT IN M BD. FT. FOR WORKING GROUP I
C          WITH BALANCED AGE CLASSES, REGENERATION CUTS.
C     OPCU(I) = ALLOWABLE ANNUAL CUT IN CU. FT. FOR WORKING GROUP I WITH
C          BALANCED AGE CLASSES, REGENERATION CUTS.
C     OPEN(I,J) = POTENTIAL COMMERCIAL THINNING IN NEXT PERIOD, ACRES OF
C          TYPE J IN BLOCK I.
C     OURS = ACRES IN WORKING CIRCLE, EXCLUDING OTHER OWNERSHIP.
C     PABR(I) = DEFORESTED ACRES IN BLOCK I, EXCLUDING UNITS WITH KNOWN
C          AREA ON INVENTORY RECORD.
C     PAFN(I,J,K) = ACRES TO RECEIVE FINAL CUT - WORKING GROUP I, BLOCK
C          J, AGE CLASS K - EXCLUDES AREAS ON INVENTORY RECORD.
C     PAIBD(I) = P.A.I. IN M BD. FT., WORKING GROUP I.
C     PAICU(I) = P.A.I. IN HUNDREDS OF CUBIC FEET, WORKING GROUP I.
C     PARG(I,J,K) = ACRES TO RECEIVE REGENERATION CUT - WORKING GROUP I,
C          BLOCK J, AGE CLASS K - EXCLUDES KNOWN AREAS.
C     PARTY(I,J) = AREA OF TYPE J IN BLOCK I, EXCLUDING UNITS WITH KNOWN
C          AREA ON INVENTORY RECORD.
C     PAS(I,J,K) = ACRES OF WORKING GROUP I, BLOCK J, AND SITE CLASS K,
C          EXCLUDING KNOWN AREAS.
C     PASP(I,J) = AREA OF WORKING GROUP I IN BLOCK J, EXCLUDING UNITS
C          WITH KNOWN AREA ON INVENTORY RECORD.
C     PBFT(I,J) = POTENTIAL YIELD IN M BD. FT. FROM THINNINGS - BLOCK I,
C          TYPE J - EXCLUDING UNITS OF KNOWN AREA.
C     PBRS(I,J) = DEFORESTED ACRES OF SITE J IN BLOCK I, EXCLUDING
C          UNITS WITH KNOWN AREA ON INVENTORY RECORD.
C     PCMT(I,J) = POTENTIAL YIELD IN MERCH. CU. FT. FROM THINNINGS -
C          BLOCK I, TYPE J - EXCLUDING UNITS OF KNOWN AREA.
C     PCTA(I,J) = POTENTIAL BD. FT. CUT FROM REGENERATION CUTS- BLOCK I,
C          TYPE J - EXCLUDING UNITS OF KNOWN AREA.
C     PCTB(I,J) = POTENTIAL BD. FT. CUT FROM FINAL CUTS - BLOCK I, TYPE
C          J - EXCLUDING UNITS OF KNOWN AREA.
C     PCCFN(I,J) = EXPECTED YIELD IN CU. FT. FROM FINAL CUTS DURING NEXT
C          PERIOD, BLOCK I, TYPE J.
C     PCCFR(I,J) = EXPECTED YIELD IN CU. FT. FROM REGENERATION CUTS NEXT
C          PERIOD, BLOCK I, TYPE J.
C     PCCUT(I) = ACRES IN AGE CLASS WITH BALANCED SERIES OF AGE CLASSES.
C     PGBD(I,J,K) = PERIODIC GROWTH IN M BD. FT. WORKING GROUP I, BLOCK
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C       J, AGE CLASS K, EXCLUDING UNITS OF KNOWN AREA.
C   PGMC(I,J,K) = PERIODIC GROWTH IN MERCH. CU. FT. WORKING GROUP I,
C       BLOCK J, AGE CLASS K, EXCLUDING UNITS OF KNOWN AREA.
C   PHLP(I,J) = POTENTIAL NONCOMMERCIAL THINNING IN NEXT PERIOD, ACRES
C       OF TYPE J IN BLOCK I. RECORDS WITH AREA - 0.0, ONLY.
C   PQOR(I) = MINIMUM SITE INDEX FOR MANAGEMENT, WORKING GROUP I.
C   PQMC(I,J) = POTENTIAL COMMERCIAL THINNING IN NEXT PERIOD, ACRES OF
C       TYPE J IN BLOCK I. RECORDS WITH AREA - 0.0, ONLY.
C   PPBF(I,J,K) = TOTAL VOLUME IN M BD. FT. FOR WORKING GROUP I, BLOCK
C       J, AGE CLASS K. EXCLUDES UNITS OF KNOWN AREA.
C   PPCR(I,J) = EXPECTED YIELD IN CU. FT. FROM REGENERATION CUTS -
C       BLOCK I, TYPE J - EXCLUDING UNITS OF KNOWN AREA.
C   PPFN(I,J) = EXPECTED YIELD IN CU. FT. FROM FINAL CUTS - BLOCK I,
C       TYPE J - EXCLUDING UNITS OF KNOWN AREA.
C   PPMC(I,J,K) = TOTAL VOLUME IN MERCH. CU. FT. FOR WORKING GROUP I,
C       BLOCK J, AND AGE CLASS K. EXCLUDES KNOWN AREAS.
C   PPTC(I,J,K) = SUM OF TOTAL CU. FT. FOR WORKING GROUP I, BLOCK J,
C       AGE CLASS K. EXCLUDES UNITS OF KNOWN AREA.
C   PRET = PERCENTAGE OF TREES RETAINED AFTER INITIAL THINNING.
C   PROD(I) = BOARD FEET PER TOTAL CUBIC FOOT - CONVERSION FACTOR.
C   PSI(I,J,K) = NUMBER OF INVENTORY PLOTS OF WORKING GROUP I, BLOCK J,
C       AND SITE CLASS K.
C   PSLV(I,J) = BD. FT. VOLUME TO BE SALVAGED - BLOCK I, TYPE J -
C       EXCLUDING UNITS OF KNOWN AREA.
C   PSPLT(I,J) = NUMBER OF INVENTORY PLOTS OF BLOCK I AND TYPE J. NOT
C       INCLUDING UNITS OF KNOWN AREA.
C   PTBF(I,J,K) = TOTAL VOLUME IN M BD. FT. FOR WORKING GROUP I, BLOCK
C       J, AND AGE CLASS K.
C   PTCU(I,J,K) = SUM OF TOTAL CU. FT. FOR WORKING GROUP I, BLOCK J,
C       AND AGE CLASS K. IN HUNDREDS OF CU. FT.
C   PTMC(I,J,K) = TOTAL VOLUME IN MERCH. CU. FT. FOR WORKING GROUP I,
C       BLOCK J, AND AGE CLASS K. IN HUNDREDS OF CU. FT.
C   PUNC(I,J) = AREA OF BLOCK I, TYPE J BELOW MINIMUM SITE QUALITY
C       FOR REGULATION, EXCLUDING UNITS OF KNOWN AREA.
C   QUAL(I) = SITE CLASSES PRESENT IN WORKING GROUP I.
C   RAGE(I,J) = ROTATION FOR WORKING GROUP I AND SITE INDEX J.
C       INCLUDES YEARS IN DELAY(I).
C   RGAC(I) = EXPECTED ACRES GIVEN REGENERATION CUTS ANNUALLY DURING
C       NEXT PERIOD, WORKING GROUP I.
C   RGBD(I) = EXPECTED ANNUAL YIELD IN M BD. FT. FROM REGENERATION
C       CUTS DURING NEXT PERIOD, WORKING GROUP I.
C   RGCU(I) = EXPECTED ANNUAL YIELD IN CU. FT. FROM REGENERATION CUTS
C       DURING NEXT PERIOD, WORKING GROUP I.
C   RINT = NUMBER OF YEARS FOR WHICH GROWTH PROJECTION IS MADE WITH
C       SINGLE COMPUTATION BY A GROWTH EQUATION.
C   ROTA = LONGEST POSSIBLE ROTATION IN YIELD TABLE.
C   SACCF = AREA OF WORKING CIRCLE IN STANDARD ACRES, FROM CU. FT.
C   SAHP(I) = POTENTIAL NONCOMMERCIAL THINNING IN NEXT PERIOD, ACRES
C       IN WORKING GROUP I.
C   SANCUT(I) = ALLOWABLE ANNUAL CUT IN ACRES, WORKING GROUP I.
C   SARETY(I,J) = AREA OF TYPE J IN BLOCK I.
C   SARSC = TOTAL AREA OF SUBCOMPARTMENTS OF A COMPARTMENT.
C   SARSP(I) = TOTAL AREA OF WORKING GROUP I, INCLUDING SHARE OF
C       DEFORESTED AREA.
C   SATH(I) = POTENTIAL COMMERCIAL THINNING IN NEXT PERIOD, ACRES IN
C       WORKING GROUP I.
C   SBARB = TOTAL BRUSHY DEFORESTED ACRES IN WORKING CIRCLE.
C   SBARE = TOTAL DEFORESTED ACRES IN WORKING CIRCLE.
C   SBARG = TOTAL GRASSY DEFORESTED ACRES IN WORKING CIRCLE.
C   SBDF = M BD. FT. IN WORKING CIRCLE.
C   SBF(I) = TOTAL M BD. FT. IN WORKING GROUP I.
C   SBFR(I) = BD. FT. FROM THINNINGS NEXT PERIOD, WORKING GROUP I.
C   SBH(I) = BD. FT. FROM REGENERATION CUTS DURING NEXT PERIOD,
C       WORKING GROUP I.
C   SBM(I,J) = BD. FT. FROM THINNING DURING NEXT PERIOD, WORKING GROUP
C       I, BLOCK J.
C   SBSV(I) = BD. FT. FROM SALVAGE NEXT PERIOD, WORKING GROUP I.
C   SCA(I,J) = BD. FT. FROM REGENERATION CUTS DURING NEXT PERIOD,
C       WORKING GROUP I, BLOCK J.
C   SCALE = ACRES IN ONE MAP SQUARE.
C   SCB(I,J) = BD. FT. FROM FINAL CUTS NEXT PERIOD, WORKING GROUP I,
C       BLOCK J.
C   SCFM = HUNDREDS OF MERCH. CU. FT. IN WORKING CIRCLE.
C   SCN(I) = EXPECTED YIELD IN CU. FT. FROM FINAL CUTS DURING NEXT
C       PERIOD, WORKING GROUP I.
C   SCNB(I,J) = EXPECTED YIELD IN CU. FT. FROM FINAL CUTS DURING NEXT
C       PERIOD, WORKING GROUP I, BLOCK J.
C   SCNT(I) = EXPECTED YIELD IN CU. FT. FROM FINAL CUTS DURING NEXT
C       PERIOD, TYPE I.
C   SCR(I) = EXPECTED YIELD IN CU. FT. FROM REGENERATION CUTS DURING
C       NEXT PERIOD, WORKING GROUP I.
C   SCRB(I,J) = EXPECTED YIELD IN CU. FT. FROM REGENERATION CUTS
C       DURING NEXT PERIOD, WORKING GROUP I, BLOCK J.
C   SCRT(I) = EXPECTED YIELD IN CU. FT. FROM REGENERATION CUTS DURING
C       NEXT PERIOD, TYPE I.
C   SCU(I,J) = CU. FT. FROM THINNING NEXT PERIOD, WORKING GROUP I,
C       BLOCK J.
C   SCUR(I) = CU. FT. FROM THINNING NEXT PERIOD, WORKING GROUP I.
C   SDBF(I) = TOTAL DIFFERENCE BETWEEN ACTUAL AND GOAL GROWING STOCKS
C       IN M BD. FT. FOR WORKING GROUP I.
C   SDMC(I) = TOTAL DIFFERENCE BETWEEN ACTUAL AND GOAL GROWING STOCK
C       IN HUNDREDS OF CU. FT. FOR WORKING GROUP I.
C   SFNL(I) = ACRES FOR FINAL CUT ANNUALLY WITH OVERWOOD AND BALANCED
C       DISTRIBUTION OF AGE CLASSES, WORKING GROUP I.
C   SFR(I) = BD. FT. FROM FINAL CUTS, NEXT PERIOD, WORKING GROUP I.
C   SHLT(I) = M BD. FT. PER ACRE OF WORKING GROUP I TO BE LEFT AS
C       SEED SOURCE.
C   SHL(I,J) = POTENTIAL NONCOMMERCIAL THINNING IN NEXT PERIOD,
C       WORKING GROUP I IN BLOCK J.
C   SHWD(I) = CU. FT. PER ACRE RETAINED AS SEED TREES OR SHELTERWOOD,
C       WORKING GROUP I.
C   SIDLA = TOTAL ALLOWABLE CUT IN ACRES FOR ONE YEAR IN A BALANCED
C       WORKING CIRCLE.
C   SIDLB = TOTAL ALLOWABLE CUT IN M BD. FT. FOR ONE YEAR IN A
C       BALANCED WORKING CIRCLE.
C   SIDLC = TOTAL ALLOWABLE CUT IN CU. FT. FOR ONE YEAR IN A BALANCED
C       WORKING CIRCLE.
C   SIDLT(I) = TOTAL ACRES IN WORKING GROUP I.
C   SMAC(I) = TOTAL ACRES IN WORKING GROUP I.
C   SMBF(I,J) = TOTAL VOLUME IN M BD. FT. FOR WORKING GROUP I, TYPE J.
C   SMC(I) = POTENTIAL COMMERCIAL THINNING IN NEXT PERIOD, ACRES OF
C       TYPE I.
C   SMCU(I,J) = CU. FT. FROM THINNING NEXT PERIOD, WORKING GROUP I,
C       BLOCK J.
C   SMPTA(I) = TOTAL ALLOWABLE CUT IN ACRES FOR ONE YEAR IN BALANCED
C       WORKING GROUP I.
C   SMPTB(I) = TOTAL M BD. FT. CUT IN ONE YEAR WITH A BALANCED SERIES
C       OF AGE CLASSES, WORKING GROUP I.
C   SMPTC(I) = TOTAL CU. FT. CUT IN ONE YEAR WITH A BALANCED SERIES
C       AGE CLASSES, WORKING GROUP I.
C   SPLT(I,J) = NUMBER OF INVENTORY PLOTS REPRESENTING TIMBER
C       TYPE J OF BLOCK I.
C   SSL(I,J) = BD. FT. FROM SALVAGE NEXT PERIOD, WORKING GROUP I,
C       BLOCK J.
C   SSPT = TOTAL OF INVENTORY PLOTS IN WORKING CIRCLE.
C   SSTAC = AREA OF WORKING CIRCLE IN STANDARD ACRES FROM BOARD FEET.
C   STACF(I) = AREA OF SITE CLASS I IN STANDARD ACRES - FROM CU. FEET.
C   STHS(I) = BD. FT. FROM THINNINGS DURING NEXT PERIOD, TYPE I.
C   STC(I) = TOTAL CU. FT. OF WORKING GROUP I IN WORKING CIRCLE.
C   STCF = TOTAL CU. FT. IN WORKING CIRCLE, IN HUNDREDS.
C   STDAC(I) = AREA OF SITE CLASS I IN STANDARD ACRES - FROM BD. FEET.
C   STFO(I) = BD. FT. FROM FINAL CUTS DURING NEXT PERIOD, TYPE I.
C   STHBF = CURRENT POTENTIAL PERIODIC YIELD FROM THINNINGS, TOTAL FOR
C       WORKING CIRCLE IN M BD. FT.
C   STHCM = CURRENT POTENTIAL PERIODIC YIELD FROM THINNINGS, TOTAL FOR
C       WORKING CIRCLE IN HUNDREDS OF CUBIC FEET.
C   STHP(I) = POTENTIAL NONCOMMERCIAL THINNING IN NEXT PERIOD, ACRES
C       OF TYPE I.
C   STHR(I) = BD. FT. FROM REGENERATION CUTS DURING NEXT PERIOD, TYPE I.
C   STLV(I) = BD. FT. FROM SALVAGE DURING NEXT PERIOD, TYPE I.
C   STNC(I) = CU. FT. FROM THINNING DURING NEXT PERIOD, TYPE I.
C   STON(I) = POTENTIAL COMMERCIAL THINNING IN NEXT PERIOD, ACRES OF
C       TYPE I.
C   STRY = STAND COMPONENT USED TO TYPE THE STAND. ENTER 1 IF THE
C       UNDERSTORY WAS USED. OTHERWISE LEAVE BLANK.
C   STYP(I) = ACRES OF TYPE I IN WORKING CIRCLE.
C   SUBBF(I,J) = GROWING STOCK GOAL FOR WORKING GROUP I, SITE CLASS J.
C       M BD. FT. IN SAWLOG TREES.
C   SUBCF(I,J) = GROWING STOCK GOAL FOR WORKING GROUP I, SITE CLASS J.
C       CUBIC FEET IN TREES BELOW SAWLOG SIZE.
C   SUBTY(I) = TYPE OF SUBCOMPARTMENT I.
C   SUMCF(I) = TOTAL GROWING STOCK GOAL FOR WORKING GROUP I IN MERCH.
C       CU. FT. SUM OF APPROPRIATE ALLCF(I,J) FOR ENTIRE STANDS.
C   SUNC = TOTAL LOW SITE ACRES IN WORKING CIRCLE.
C   TBA(I) = BASAL AREA AFTER THINNING TO SPECIFIED LEVEL NOW (I=1) OR
C       IN TIME YEARS (I=2).
C   TBD(I) = M BD. FT. AFTER THINNING TO SPECIFIED LEVEL NOW (I=1) OR
C       IN TIME YEARS (I=2).
C   TCF(I) = TOTAL CUBIC FEET IN BLOCK I.
C   TCM(I) = HUNDREDS OF CU. FT. AFTER THINNING TO SPECIFIED LEVEL NOW
C       (I=1) OR IN TIME YEARS (I=2).
C   TCSP(I,J) = TOTAL CU. FT. OF WORKING GROUP I IN BLOCK J.
C   TDM(I) = AVERAGE D.B.H. AFTER THINNING TO SPECIFIED LEVEL NOW
C       (I=1) OR IN TIME YEARS (I=2).
C   TEM = TEMPORARY VARIABLE, ASSIGNED MEANINGS AS NEEDED.
C   THAC(I) = POSSIBLE ACRES TO THIN ANNUALLY DURING NEXT PERIOD,
C       WORKING GROUP I.
C   THB = AVERAGE POTENTIAL VOLUME FROM THINNING, M BD. FT.
C   THBD(I) = EXPECTED ANNUAL YIELD IN M BD. FT. FROM THINNINGS DURING
C       NEXT PERIOD, WORKING GROUP I.
C   THC = AVERAGE POTENTIAL VOLUME FROM THINNING, HUNDREDS OF CU. FT.
C   THCU(I) = EXPECTED ANNUAL YIELD IN CU. FT. FROM THINNINGS DURING
C       NEXT PERIOD, WORKING GROUP I.
C   THIN(I) = GROWING STOCK LEVEL, INITIAL THINNING, WORKING GROUP I.
C   TIME = NUMBER OF YEARS IN PLANNING PERIOD. BASIS FOR WORK INDEX.
C   TMBR = TOTAL TIMBERED AREA IN WORKING CIRCLE.
C   TMPO = TOTAL AREA OF FOREST TYPES IN WORKING CIRCLE, INCLUDING
C       NONSTOCKED TYPES.
C   TOT(I) = TOTAL CUBIC FEET IN OVERSTORY(I-1) OR UNDERSTORY(I-2).
C   TOTAC(I) = TOTAL ACRES EXPECTED TO BE TREATED IN ONE YEAR DURING
C       NEXT PERIOD, WORKING GROUP I.
C   TOTBD(I) = EXPECTED TOTAL ANNUAL YIELD IN M BD. FT. DURING NEXT
C       PERIOD, WORKING GROUP I.
C   TOTC = TOTAL CUBIC FEET REMOVED PER ACRE.
C   TOTCU(I) = EXPECTED TOTAL ANNUAL YIELD IN CU. FT. DURING NEXT
C       PERIOD, WORKING GROUP I.
C   TOTO = TOTAL CUBIC FEET PER ACRE BEFORE THINNING.
C   TOTT = TOTAL CUBIC FEET PER ACRE AFTER THINNING.
C   TPB(I,J) = NUMBER OF INVENTORY PLOTS, WORKING GROUP I, BLOCK J.
C   TVL(I) = TOTAL CU. FT. AFTER THINNING TO SPECIFIED LEVEL NOW (I=1)
C       OR IN TIME YEARS (I=2).
C   TYPNM(I) = DESCRIPTION OF VEGETATIVE TYPE OR USE TYPE NUMBER I.
C   UNCML(I,J) = AREA OF BLOCK I AND TIMBER TYPE J BELOW MINIMUM
C       SITE QUALITY FOR TIMBER MANAGEMENT AND REGULATION.
C   UNIT(I) = NUMBER OF MAP SQUARES IN SUBCOMPARTMENT I.
C   VLBF(I) = VOLUME IN M BD. FT. CUT FROM SITE I.
C   VLCU(I) = VOLUME IN CU. FT. CUT FROM SITE I.
C   WHEN = YEAR OF FIRST GROWING SEASON AFTER INVENTORY WAS MADE.
C   WORK = CODE FOR TREATMENT IN NEXT PERIOD, ASO
C       0 = DO NOTHING THIS PERIOD
C       1 = PLANT OR SEED
C       2 = THIN
C       3 = SALVAGE
C       4 = REGENERATION CUT
C       5 = REMOVE SEED TREES OR SHELTERWOOD
C       6 = REMOVE OVERWOOD AND THIN RESIDUAL
C
      COMMON ABFAG(3,15),ACBAR(5),ACSI(3,5,10),ACSP(3,5),ALLCF(3,10),AMC
     1AG(3,15),ANCUT(3,10),ARBK(5),AREA(3,10),BARSI(5,10),BFAGE(3,15),BF
     2TH(5,12),BFMRCH,CFAGE(3,15),CFBF(3,10),CMTH(5,12),COMBF(3),COMCU,C
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      3UTA(5,12),CUTB(5,12),CYCL,DATE(3),DLEV(3),FINL(3),FORET(3),GRBD(3,
     45,15),GRMC(3,5,15),GROWB(3),GROWC(3),GVLBF(3),GVLCU(3),MIN,NBK,NCM
     5P,NSBK(5),NSI(3),NSUB,OPEN(5,12),POOR(3),PRET,RAGE(3,10),RINT,ROTA
     6,SARETY(5,20),SARSP(3),SBARB,SBARE,SBARG,SBF(3),SHELT(3),SHWC(3),S
     7LAND,SLVG(5,12),SMC(3),SMSP(3),STYP(20),SUBBF(3,10),SUBCF(3,10),SU
     8MCF(3),THIN(3),TMBR,TMPO,TYPNM(20),DELAY(3),ACFNL(3,5,15),ACRGN(3,
     95,15),TIME,PDCFR(5,12),PDCFN(5,12),OPCU(3),FNCU(3),CUINT(3),ACINT(
     13),FNBD(3),BFINT(3),OPBD(3),TEM,MNK,KNO,FCTR(2),PROD(2),KAK,VDM(2)
     2,ADJ(3),ALOWC(3),ALWBF(3),BDMAI(3),CUMAI(3),PAIBD(3),PAICU(3),OBHO
     3,DENO,REST,DBHT,BAST,NWGP,HELP(5,12),BA(2)
C
      CALL BASIS
C
C CALL APPROPRIATE ROUTINE TO COMPUTE AREAS.
C
      CALL AREA2
C
C COMPUTE PRESENT VOLUMES, FUTURE GROWTH, ETC. FROM INVENTORY DATA.
C
      CALL GOT
C
C COMPUTE GROWING STOCK GOALS AND AREA CONTROL.
C
      CALL GOAL
C
C DETERMINE DIFFERENCES BETWEEN PRESENT FOREST AND GOALS. PRINT A
C GUIDE TO MANAGEMENT.
C
      CALL GUIDE
      CALL EXIT
      END
      SUBROUTINE BASIS
C
C TO INITIALIZE OR READ VARIABLES THAT APPLY TO THE WORKING CIRCLE.
C
      COMMON ABFAG(3,15),ACBAR(5),ACSI(3,5,10),ACSP(3,5),ALLCF(3,10),AMC
     1AG(3,15),ANCUT(3,10),ARBK(5),AREA(3,10),BARSI(5,10),BFAGE(3,15),BF
     2TH(5,12),BFMRCH,CFAGE(3,15),CFBF(3,10),CMTH(5,12),COMBF(3),COMCU,C
     3UTA(5,12),CUTB(5,12),CYCL,DATE(3),DLEV(3),FINL(3),FORET(3),GRBD(3,
     45,15),GRMC(3,5,15),GROWB(3),GROWC(3),GVLBF(3),GVLCU(3),MIN,NBK,NCM
     5P,NSBK(5),NSI(3),NSUB,OPEN(5,12),POOR(3),PRET,RAGE(3,10),RINT,ROTA
     6,SARETY(5,20),SARSP(3),SBARB,SBARE,SBARG,SBF(3),SHELT(3),SHWC(3),S
     7LAND,SLVG(5,12),SMC(3),SMSP(3),STYP(20),SUBBF(3,10),SUBCF(3,10),SU
     8MCF(3),THIN(3),TMBR,TMPO,TYPNM(20),DELAY(3),ACFNL(3,5,15),ACRGN(3,
     95,15),TIME,PDCFR(5,12),PDCFN(5,12),OPCU(3),FNCU(3),CUINT(3),ACINT(
     13),FNBD(3),BFINT(3),OPBD(3),TEM,MNK,KNO,FCTR(2),PROD(2),KAK,VDM(2)
     2,ADJ(3),ALOWC(3),ALWBF(3),BDMAI(3),CUMAI(3),PAIBD(3),PAICU(3),OBHO
     3,DENO,REST,DBHT,BAST,NWGP,HELP(5,12),BA(2)
C
C INITIALIZE VARIABLES APPLICABLE TO THE WORKING CIRCLE.
C
      MNK = 0
      NSUB = 0
      SBARB = 0.0
      SBARE = 0.0
      SBARG = 0.0
      SLAND = 0.0
      TEM = 0.0
      TMBR = 0.0
      TMPO = 0.0
      DO 1 I=1,5
      ACBAR(I) = 0.0
      ARBK(I) = 0.0
      NSBK(I) = 0
      DO 1 J=1,20
    1 SARETY(I,J) = 0.0
      DO 2 I=1,20
    2 STYP(I) = 0.0
      DO 3 I=1,3
      ACINT(I) = 0.0
      ALOWC(I) = 0.0
      ALWBF(I) = 0.0
      BDMAI(I) = 0.0
      BFINT(I) = 0.0
      CUINT(I) = 0.0
      CUMAI(I) = 0.0
      FNBD(I) = 0.0
      FNCU(I) = 0.0
      OPBD(I) = 0.0
      OPCU(I) = 0.0
      PAIBD(I) = 0.0
      PAICU(I) = 0.0
      DO 3 J=1,5
      ACSP(I,J) = 0.0
      DO 3 K=1,10
    3 ACSI(I,J,K) = 0.0
      DO 4 I=1,3
      DO 4 J=1,5
      DO 4 K=1,15
      ACFNL(I,J,K) = 0.0
      ACRGN(I,J,K) = 0.0
      GRBD(I,J,K) = 0.0
    4 GRMC(I,J,K) = 0.0
      DO 5 I=1,5
      DO 5 J=1,10
    5 BARSI(I,J) = 0.0
      DO 6 I=1,3
      GVLBF(I) = 0.0
      GVLCU(I) = 0.0
      NSI(I) = 0
      SARSP(I) = 0.0
      SUMCF(I) = 0.0
      SBF(I) = 0.0
      SMC(I) = 0.0
      SMSP(I) = 0.0
      DO 6 J=1,10
      ALLCF(I,J) = 0.0
      ANCUT(I,J) = 0.0
      AREA(I,J) = 0.0
      CFBF(I,J) = 0.0
      SUBBF(I,J) = 0.0
      SUBCF(I,J) = 0.0
    6 CONTINUE
      DO 7 I=1,3
      DO 7 J=1,15
      ABFAG(I,J) = 0.0
      AMCAG(I,J) = 0.0
      BFAGE(I,J) = 0.0
    7 CFAGE(I,J) = 0.0
      DO 8 I=1,5
      DO 8 J=1,12
      BFTH(I,J) = 0.0
      CMTH(I,J) = 0.0
      CUTA(I,J) = 0.0
      CUTB(I,J) = 0.0
      HELP(I,J) = 0.0
      OPEN(I,J) = 0.0
      PDCFN(I,J) = 0.0
      PDCFR(I,J) = 0.0
      SLVG(I,J) = 0.0
    8 CONTINUE
      DO 9 I=1,2
      BA(I) = 0.0
      FCTR(I) = 0.0
      PROD(I) = 0.0
      VDM(I) = 0.0
    9 CONTINUE
C
C READ INITIAL VALUES OF APPROPRIATE VARIABLES.
C
      READ (5,14) (FORET(I),I=1,3)
   14 FORMAT (3A8)
      READ (5,16) (TYPNM(I),I=1,20)
   16 FORMAT (8A10)
      READ (5,18) NBK,NCMP,NWGP,MIN
   18 FORMAT (4I4)
      READ (5,20) ROTA,CYCL,RINT,COMCU,BFMRCH,TIME
   20 FORMAT (6F8.3)
      READ (5,23) GROWB(1),GROWC(1),FINL(1),DLEV(1),THIN(1),POOR(1),SHEL
     1T(1),SHWD(1),COMBF(1),DELAY(1),ADJ(1)
   23 FORMAT (2F5.3,9F4.1)
      READ (5,23) GROWB(2),GROWC(2),FINL(2),DLEV(2),THIN(2),POOR(2),SHEL
     1T(2),SHWD(2),COMBF(2),DELAY(2),ADJ(2)
C
C READ ROTATION LENGTHS. ENTER RAGE(KAK,1) FOR SITE INDEX 10, RAGE(KAK,2)
C FOR SITE INDEX 20, ETC., EVEN THOUGH SITES BELOW POOR(KAK) WILL NOT BE
C MANAGED. THIS KEEPS ARRAYS IN ORDER EVEN IF POOR(KAK) VARIES BY
C WORKING GROUP.
C
      READ (5,24) (RAGE(1,I),I=1,10)
   24 FORMAT (10F4.0)
      READ (5,24) (RAGE(2,I),I=1,10)
      READ (5,14) (DATE(I),I=1,3)
C
C PRINT PAGE TYPE 4 - RECORD OF VALUES READ BY THIS ROUTINE.
C
      WRITE (6,39)
   39 FORMAT (1H1,///,61X,11HPAGE TYPE 4)
      WRITE (6,40)
   40 FORMAT (1HO,39X,53HRECORD OF MANAGEMENT DECISIONS AND CURRENT COND
     1ITIONS)
      WRITE (6,41) (FORET(I),I=1,3)
   41 FORMAT (1H ,56X,3A8,//)
      WRITE (6,42) NBK,NCMP
   42 FORMAT (1H ,10X,18HNUMBER OF BLOCKS -,I3,32X,24HNUMBER OF COMPARTM
     1ENTS -,I4)
      WRITE (6,43) MIN,CYCL
   43 FORMAT (1HO,10X,31HMINIMUM AGE FOR GROWING STOCK -,I3,19X,32HLENGT
     1H OF CUTTING CYCLE, YEARS -,F5.0)
      WRITE (6,44) BFMRCH,RINT
   44 FORMAT (1HO,10X,37HMINIMUM M BD. FT. FOR GROWING STOCK -,F5.1,11X,
     136HLENGTH OF PREDICTION PERIOD, YEARS -,F4.0)
      WRITE (6,45) TIME
   45 FORMAT (1HO,10X,34HLENGTH OF PLANNING PERIOD, YEARS -,F4.0,/)
      WRITE (6,46)
   46 FORMAT (1HO,58X,4HPINE,10X,6HSPRUCE)
      WRITE (6,47)
   47 FORMAT (1H ,58X,5HGROUP,9X,5HGROUP)
      WRITE (6,48) POOR(1),POOR(2)
   48 FORMAT (1HO,10X,31HLOWEST SITE CLASS TO BE MANAGED,14X,F7.1,8X,F7.
     11)
      WRITE (6,49) ADJ(1),ADJ(2)
   49 FORMAT (1HO,10X,34HLENGTH OF ADJUSTMENT PERIOD, YEARS,11X,F7.1,8X,
     1F7.1)
      WRITE (6,50) SHELT(1),SHELT(2)
   50 FORMAT (1HO,10X,35HM BD. FT. TO BE LEFT AS SEED SOURCE,10X,F7.1,8X
     1,F7.1)
      WRITE (6,51) SHWD(1),SHWD(2)
   51 FORMAT (1HO,10X,33HCU. FT. TO BE LEFT AS SEED SOURCE,12X,F7.1,8X,F
     17.1)
      WRITE (6,53) FINL(1),FINL(2)
   53 FORMAT (1HO,10X,38HYEARS TO LEAVE OVERWOOD AS SEED SOURCE,7X,F7.1,
     18X,F7.1)
      WRITE (6,55) DELAY(1),DELAY(2)
   55 FORMAT (1HO,10X,37HEXPECTED DELAY IN REGENERATION, YEARS,8X,F7.1,8
     1X,F7.1)
      WRITE (6,57) GROWB(1),GROWB(2)
   57 FORMAT (1HO,10X,38HBD. FT. GROWTH OF SHELTERWOOD, PERCENT,7X,F8.2,
     17X,F8.2)
      WRITE (6,58) GROWC(1),GROWC(2)
   58 FORMAT (1HO,10X,38HCU. FT. GROWTH OF SHELTERWOOD, PERCENT,7X,F8.2,
     17X,F8.2)
      WRITE (6,60) THIN(1),THIN(2)
   60 FORMAT (1HO,10X,35HSTOCKING LEVEL FOR INITIAL THINNING,10X,F7.1,8X
     1,F7.1)
      WRITE (6,61) DLEV(1),DLEV(2)
   61 FORMAT (1HO,10X,36HSTOCKING LEVEL, SUBSEQUENT THINNINGS,9X,F7.1,8X
     1,F7.1)
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      WRITE (6,63) CMMBF(1),CMMBF(2)
   63 FORMAT (1HC,10X,33HMINIMUM COMMERCIAL CUT, M BD. FT.,12X,F7.1,8X,F
     17.1)
      WRITE (6,64) CMCU,CMCI
   64 FORMAT (1HC,12X,31HMINIMUM COMMERCIAL CUT, CU. FT.,14X,F7.1,8X,F7.
     11)
      WRITE (6,70)
   70 FORMAT (1HO,//,11X,22HCUBIC FEET IN HUNDREDS)
      RETURN
      END
      SUBROUTINE AREA2
C
C TO COMPUTE TYPE AREAS WHEN COMPARTMENT AREAS ARE NOT KNOWN.
C
      COMMON ABEAG(3,15),ACBAR(5),ACSI(3,5,10),ACSP(3,5),ALLCE(3,10),AMC
     1AG(3,15),ANCUT(3,10),ARBK(5),AREA(3,10),BAPSI(5,10),BEAGE(3,15),BF
     2TH(5,12),BFMRCH,CFAGE(3,15),CFBF(3,10),CMTH(5,12),COMBE(3),COMCU,C
     3UTA(5,12),CUTH(5,12),CYCL,DATE(3),ELEV(3),FINE(3),FORET(3),GRBD(3,
     45,15),GRMC(3,5,15),GRCWB(3),GROWC(3),GVLBF(3),GVLCU(3),MIN,NBK,NCM
     5P,NSBK(5),NSI(3),NSUB,OPEN(5,12),PCOR(3),PRET,RAGE(3,10),RINT,ROTA
     6,SAFETY(5,20),SARSP(3),SBARB,SBARE,SBARG,SBF(3),SHELT(3),SHWC(3),S
     7LAND,SLVG(5,12),SMC(3),SMSP(3),STYP(20),SUBBF(3,10),SUBCF(3,10),SU
     8MCF(3),THIN(3),TMBR,TMPO,TYPNM(20),DELAY(3),ACENE(3,5,15),ACRGN(3,
     95,15),TIME,PDCFR(5,12),PDCFN(5,12),OPCU(3),FNCU(3),CUINT(3),ACINT(
     13),FNBD(3),BFINT(3),OPBD(3),TEM,MNK,KNO,FCTR(2),PROD(2),KAK,VOM(2)
     2,ADJ(3),ALOWC(3),ALWBF(3),BDMAI(3),CUMAI(3),PAIBD(3),PAICU(3),DBHO
     3,DENO,REST,DBHT,BAST,NWGP,HELP(5,12),BA(2)
C
      DIMENSION SPL(5),SPLT(5,12),TMTY(5),DBH(2),HT(2),DEN(2),AGE(2)
C
C INITIALIZE VARIABLES DEFINED BY THIS SUBROUTINE.
C
      DO 2 I=1,5
      SPL(I) = 0.0
      TMTY(I) = 0.0
      DO 2 J=1,12
    2 SPLT(I,J) = 0.0
      TMPO = 0.0
C
C READ AREAS OF BLOCKS AND OF NON-TIMBER TYPES.
C
      READ (5,5) (ARBK(I),I=1,NBK)
    5 FORMAT (5F8.1)
      DO 7 I=1,NBK
      READ (5,6) (SARETY(I,J),J=13,20)
    6 FORMAT (8F8.1)
    7 CONTINUE
C
C COMPUTE TOTAL AREAS OCCUPIED BY TIMBER TYPES.
C
      DO 11 I=1,NBK
      TEM = 0.0
      DO 10 J=13,20
   10 TEM = TEM + SARETY(I,J)
      TMTY(I) = ARBK(I) - TEM
   11 TMPO = TMPO + TMTY(I)
C
C READ INVENTORY RECORDS TO COUNT THEM BY BLOCK, TYPE, ETC. LAST
C RECORD HAS ZERO OR VERY LARGE VALUE FOR IBK TO STOP PROCESSING.
C LOGICAL UNIT 4 HOLDS THE INVENTORY TAPE.
C
   15 READ (4,16) IBK,KOMP,ISUB,QTR1,QTR2,SECT,TOWN,RANG,SITE,STRY,NTYP,
     1WCRK,DBH(1),HT(1),DEN(1),AGE(1),DBH(2),HT(2),DEN(2),AGE(2),ACRE,WH
     2ER
   16 FORMAT (12,I4,I3,3A3,2A4,F4.0,F2.0,I3,F3.0,F4.1,F3.0,F5.0,F4.0,F4.
     11,F3.0,F5.0,F4.0,F5.1,F5.0)
      IF(IBK .EQ. 0 .OR. IBK .GT. NBK) GO TO 20
      IF(ACRE .EQ. 0.0) GO TO 17
      SARETY(IBK,NTYP) = SARETY(IBK,NTYP) + ACRE
      TMTY(IBK) = TMTY(IBK) - ACRE
      GO TO 15
   17 SPLT(IBK,NTYP) = SPLT(IBK,NTYP) + 1.0
      GO TO 15
C
C TOTAL PLOTS BY BLOCK.
C
   20 DO 21 I=1,NBK
      DO 21 J=1,12
   21 SPL(I) = SPL(I) + SPLT(I,J)
C
C COMPUTE TYPE AREAS WITHIN EACH BLOCK.
C
      DO 26 I=1,NBK
      IF(SPL(I) .EQ. 0.0) GO TO 26
      TEM = TMTY(I) / SPL(I)
      DO 25 J=1,12
      SARETY(I,J) = SARETY(I,J) + (SPLT(I,J) * TEM)
   25 CONTINUE
   26 CONTINUE
C
C SUM TYPE AREAS TO GET BLOCK AND WORKING CIRCLE TOTALS.
C
      DO 30 I=1,NBK
      DO 30 J=1,20
      STYP(J) = STYP(J) + SARETY(I,J)
   30 CONTINUE
      DO 31 I=1,NBK
      SBARB = SBARB + SARETY(I,11)
      SBARG = SBARG + SARETY(I,12)
      ACBAR(I) = ACBAR(I) + SARETY(I,11) + SARETY(I,12)
   31 CONTINUE
      DO 32 I=1,NBK
      DO 32 J=1,5
      MNK = J + 5
      ACSP(1,I) = ACSP(1,I) + SARETY(I,J)
   32 ACSP(2,I) = ACSP(2,I) + SARETY(I,MNK)
      SBARE = SBARB + SBARG
      DO 33 I=1,NBK
      SLAND = SLAND + ARBK(I)
      DO 33 I=1,NWGP
      SMSP(I) = SMSP(I) + ACSP(I,I
   33 CONTINUE
C
C WRITE PAGE TYPE 5 - AREAS BY TYPE - AC. WORKING CIR. BY.
C
      WRITE (6,34)
   34 FORMAT (1H1,////,54X,11HPAGE TYPE 5)
      WRITE (6,35) (FORET(I),I=1,3)
   35 FORMAT (1HC,48X,32HAREAS OF TYPES IN WORKING CIRCLE/1H ,54X,10HFINE
     10,30X,10HCOVER TYPE,11X,5HACRES,6X,1H*,6X,10HCOVER TYPE,11X,5HACRE
     2S,/)
      DO 37 I=1,10
      J = I + 10
      WRITE (6,36) I,TYPNM(I),STYP(I),J,TYPNM(J),STYP(J)
   36 FORMAT (1HC,28X,I2,2X,A10,4X,F12.1,4X,1H*,4X,I2,2X,A10,4X,F12.1)
   37 CONTINUE
      WRITE (6,38) SLAND
   38 FORMAT (1HO,73X,10HTOTAL AREA,2X,F12.1)
      WRITE (6,39) SMSP(1),SMSP(2),SBARE
   39 FORMAT (1HC,//,22X,12HPINE GROUP -,F12.1,6X,14HSPRUCE GROUP -,F12.
     11,9X,18HDEFORESTED ACRES -,F12.1)
C
C PRINT PAGE TYPE 6 - SUMMARY OF AREAS BY BLOCK AND WORKING CIRCLE.
C
      WRITE (6,40)
   40 FORMAT (1H1,////,59X,11HPAGE TYPE 6)
      WRITE (6,41)
   41 FORMAT (1HC,44X,40HTOTAL AREAS OF BLOCKS AND WORKING CIRCLE)
      WRITE (6,42) (FORET(I),I=1,3)
   42 FORMAT (1H ,53X,3A8)
      WRITE (6,43)
   43 FORMAT (1HO,//,4X,5HBLOCK,10X,5HTOTAL,14X,44H****** PLANTABLE ACRE
     1S FOREST SOIL **********,10X,24HFOREST AND REGENERATING)
      WRITE (6,44)
   44 FORMAT (1H ,4X,3HNO.,11X,5HACRES,14X,6HBRUSHY,13X,6HGRASSY,14X,5HT
     1OTAL,19X,4HPINE,13X,6HSPRUCE,//)
      DO 51 I=1,NBK
      WRITE (6,50) I,ARBK(I),SAFETY(I,11),SAFETY(I,12),ACBAR(I),ACSP(1,I
     1),ACSP(2,I)
   50 FORMAT (1HC,4X,I2,8X,F10.1,10X,F10.1,9X,F10.1,9X,F10.1,13X,F10.1,9
     1X,F10.1)
   51 CONTINUE
      WRITE (6,52) SLAND,SBARB,SBARG,SBARE,SMSP(1),SMSP(2)
   52 FORMAT (1HO,//,4X,5HTOTAL,6X,F10.1,10X,F10.1,9X,F10.1,9X,F10.1,13X
     1,F10.1,9X,F10.1)
      WRITE (6,60)
   60 FORMAT (1HO,///,55X,21HDESIGNATIONS OF TYPES)
      DO 62 I=1,10
      J = I + 10
      WRITE (6,61) I,TYPNM(I),J,TYPNM(J)
   61 FORMAT (1HC,43X,I2,4X,A10,6X,1H*,6X,I2,4X,A10)
   62 CONTINUE
      RETURN
      END
      SUBROUTINE VOLS
C
C TO CONVERT TOTAL CU. FT. TO MERCH. CU. FT. AND TO BD. FT.
C
      COMMON ABEAG(3,15),ACBAR(5),ACSI(3,5,10),ACSP(3,5),ALLCE(3,10),AMC
     1AG(3,15),ANCUT(3,10),ARBK(5),AREA(3,10),BAPSI(5,10),BEAGE(3,15),BF
     2TH(5,12),BFMRCH,CFAGE(3,15),CFBF(3,10),CMTH(5,12),COMBE(3),COMCU,C
     3UTA(5,12),CUTH(5,12),CYCL,DATE(3),ELEV(3),FINE(3),FORET(3),GRBD(3,
     45,15),GRMC(3,5,15),GRCWB(3),GROWC(3),GVLBF(3),GVLCU(3),MIN,NBK,NCM
     5P,NSBK(5),NSI(3),NSUB,OPEN(5,12),PCOR(3),PRET,RAGE(3,10),RINT,ROTA
     6,SAFETY(5,20),SARSP(3),SBARB,SBARE,SBARG,SBF(3),SHELT(3),SHWC(3),S
     7LAND,SLVG(5,12),SMC(3),SMSP(3),STYP(20),SUBBF(3,10),SUBCF(3,10),SU
     8MCF(3),THIN(3),TMBR,TMPO,TYPNM(20),DELAY(3),ACENE(3,5,15),ACRGN(3,
     95,15),TIME,PDCFR(5,12),PDCFN(5,12),OPCU(3),FNCU(3),CUINT(3),ACINT(
     13),FNBD(3),BFINT(3),OPBD(3),TEM,MNK,KNO,FCTR(2),PROD(2),KAK,VOM(2)
     2,ADJ(3),ALOWC(3),ALWBF(3),BDMAI(3),CUMAI(3),PAIBD(3),PAICU(3),DBHO
     3,DENO,REST,DBHT,BAST,NWGP,HELP(5,12),BA(2)
C
      DO 2 I=1,2
      FCTR(I) = 0.0
    2 PROD(I) = 0.0
      IF(KAK .EQ. 2) GO TO 20
      DO 14 I=1,KNO
C
C COMPUTE MERCH. CU. FT. OF FIRST SPECIES.
C
      IF(VOM(I) .LT. 5.0) GO TO 14
      IF(VOM(I) .GT. 6.7) GO TO 4
      FCTR(I) = 0.26612 * VOM(I) - 1.12689
      GO TO 8
    4 IF(VOM(I) .GT. 10.4) GO TO 6
      FCTR(I) = 3.46993 - 0.12017 * VOM(I) - 13.41984 / VOM(I)
      GO TO 8
    6 FCTR(I) = 0.99666 - 0.66932 / VOM(I)
C
C COMPUTE BD. FT. OF FIRST SPECIES.
C
    8 IF(VOM(I) .LT. 8.0) GO TO 14
      IF(VOM(I) .GT. 11.9) GO TO 10
      PROD(I) = 0.87783 * VOM(I) + 0.00886 * BA(I) - 7.27457
      GO TO 14
   10 PROD(I) = 5.10752 + 0.10712 * VOM(I) + 0.00185 * BA(I) - 36.20229
     1 / VOM(I)
   14 CONTINUE
      RETURN
   20 DO 32 I=1,KNO
C
C COMPUTE MERCH. CU. FT. OF SECOND SPECIES.
C
      IF(VOM(I) .LT. 5.0) GO TO 32
      IF(VOM(I) .GT. 6.8) GO TO 22
      FCTR(I) = 0.28253 * VOM(I) - 1.19723
      GO TO 26
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   22 IF(VDM(I) .GT. 10.0) GO TO 24
      FCTR(I) = 3.17119 - 11.77668 / VDM(I) - 0.10560 * VDM(I)
      GO TO 26
   24 FCTR(I) = 0.98488 - 0.45681 / VDM(I)
C
C COMPUTE BD. FT. OF SECOND SPECIES
C
   26 IF(VDM(I) .LT. 8.0) GO TO 32
   28 IF(VDM(I) .GT. 11.5) GO TO 30
      PROD(I) = 0.86587 * VDM(I) - 6.54505
      GO TO 32
   30 PROD(I) = 11.21673 - 71.48795 / VDM(I) - 0.13545 * VDM(I)
   32 CONTINUE
      RETURN
      END

      SUBROUTINE CUTS
C
C TO ESTIMATE INCREASE IN AVERAGE D.B.H. DUE TO THINNING.
C
      COMMON ABFAG(3,15),ACBAR(5),ACSI(3,5,10),ACSP(3,5),ALLCF(3,10),AMC
     1AG(3,15),ANCUT(3,10),ARBK(5),AREA(3,10),BARSI(5,10),BFAGE(3,15),BF
     2TH(5,12),BFMRCH,CFAGE(3,15),CFBF(3,10),CMTH(5,12),COMBF(3),COMCU,C
     3UTA(5,12),CUTB(5,12),CYCL,DATE(3),DLEV(3),FINL(3),FORET(3),GRBD(3,
     45,15),GRMC(3,5,15),GROWB(3),GROWC(3),GVLBF(3),GVLCU(3),MIN,NBK,NCM
     5P,NSBK(5),NSI(3),NSUB,OPEN(5,12),POOR(3),PRET,RAGE(3,10),RINT,ROTA
     6,SARETY(5,20),SARSP(3),SBARB,SBARE,SBARG,SBF(3),SHELT(3),SHWD(3),S
     7LAND,SLVG(5,12),SMC(3),SMSP(3),STYP(20),SUBBF(3,10),SUBCF(3,10),SU
     8MCF(3),THIN(3),TMBR,TMPO,TYPNM(20),DELAY(3),ACFNL(3,5,15),ACRGN(3,
     95,15),TIME,PDCFR(5,12),PDCFN(5,12),OPCU(3),FNCU(3),CUINT(3),ACINT(
     13),FNBD(3),BFINT(3),OPBD(3),TEM,MNK,KNO,FCTR(2),PROD(2),KAK,VDM(2)
     2,ADJ(3),ALOWC(3),ALWBF(3),BOMAI(3),CUMAI(3),PAIBO(3),PAICU(3),DBHO
     3,DENO,REST,DBHT,BAST,NWGP,HELP(5,12),BA(2)
C
      IF(DBHO .LT. 9.4) GO TO 30
C
C COMPUTE D.B.H. IF DBHO IS LARGE ENOUGH FOR BASAL AREA TO REMAIN CONSTANT.
C
      PRET = 100.0
      DO 21 KJ=1,100
      IF(PRET .LT. 50.0) GO TO 5
      IF(KAK .EQ. 2) GO TO 1
      DBHE = 0.73365 + 1.02008 * DBHO - 0.01107 * (PRET - 50.0) - 0.0001
     14 * (PRET - 50.0) * (PRET - 50.0)
      GO TO 11
    1 DBHE = DBHO + 1.05308 - 0.02106 * (PRET - 50.0)
      GO TO 11
    5 IF(KAK .EQ. 2) GO TO 6
      PDBHE = 0.49401 + 0.71890 * ALOG10(DBHO) - 0.22530 * ALOG10(PRET)
     1 + 0.12616 * ALOG10(DBHO) * ALOG10(PRET)
      GO TO 10
    6 PDBHE = 0.26136 + 0.93849 * ALOG10(DBHO) - 0.09292 * ALOG10(PRET)
   10 DBHE = 10.0 ** PDBHE
   11 IDBHE = DBHE  * 10.0 + 0.5
      DBHE = IDBHE
      DBHE = DBHE * 0.1
      DENE = DENO * PRET * 0.01
      NDENE = DENE + 0.5
      DENE = NDENE
      BASE = 0.0054542 * DBHE * DBHE * DENE
      NBASE = BASE * 10.0 + 0.5
      BASE = NBASE
      BASE = BASE * 0.1
      TMPY = 0.0054542 * DBHE * DBHE
      TEM = BASE - REST
      IF(TEM .LE. TMPY) GO TO 70
      IF(TEM .LT. 4.0) GO TO 20
      PRET = PRET - 1.0
      GO TO 21
   20 PRET = PRET - 0.3
   21 CONTINUE
      GO TO 70
C
C COMPUTE D.B.H. IF BASAL AREA INCREASES WITH D.B.H.
C
   30 PRET = 40.0
      IF(DBHO .GT. 7.0) PRET = 70.0
      DO 65 J=1,100
      IF(PRET .GE. 50.0) GO TO 40
      IF(KAK .EQ. 2) GO TO 35
      PDBHE = 0.49401 + 0.71890 * ALOG10(DBHO) - 0.22530 * ALOG10(PRET)
     1 + 0.12616 * ALOG10(DBHO) * ALOG10(PRET)
      GO TO 36
   35 PDBHE = 0.26136 + 0.93849 * ALOG10(DBHO) - 0.09292 * ALOG10(PRET)
   36 DBHE = 10.0 ** PDBHE
      GO TO 45
   40 IF(KAK .EQ. 2) GO TO 41
      DBHE = 0.73365 + 1.02008 * DBHO - 0.01107 * (PRET - 50.0) - 0.0001
     14 * (PRET - 50.0) * (PRET - 50.0)
      GO TO 45
   41 DBHE = DBHO + 1.05308 - 0.02106 * (PRET - 50.0)
   45 IDBHE = DBHE * 10.0 + 0.5
      DBHE = IDBHE
      DBHE = DBHE * 0.1
      DENE = DENO * (PRET * 0.01)
      NDENE = DENE + 0.5
      DENE = NDENE
      BASE = 0.0054542 * DBHE * DBHE * DENE
      NBASE = BASE * 10.0 + 0.5
      BASE = NBASE
      BASE = BASE * 0.1
      BREAK = 49.9 * REST / 80.0
      IF(BASE .GT. BREAK) GO TO 50
      DBHP = (80.0 / REST) * (0.08682 * BASE) + 0.94636
      GO TO 52
   50 BUST = 66.2 * (REST / 80.0)
      IF(BASE .GT. BUST) GO TO 51
      DBHP = (80.0 / REST) * (0.10938 * BASE) - 0.17858
      GO TO 52
   51 TMPY = BASE * (80.0 / REST)
      TEM = TMPY * TMPY
      DBHP = 19.14740 * TMPY - 0.26673 * TEM + 0.0012539 * TEM * TMPY
     1 - 448.76833
      IF(TMPY .GT. 80.0) DBHP = DBHO + 0.8
   52 IDBHP = DBHP * 10.0 + 0.5
      IDBHP = IDBHP
      DBHP = DBHP * 0.1
      IF(DBHP - DBHE) 60,70,61
   61 PRET = PRET * 1.02
      GO TO 65
   60 PRET = PRET * 0.98
   65 CONTINUE
   70 PORT = DBHE
C
C COMPUTE POST-THINNING BASAL AREA.
C
      IF(DBHT .GT. 5.0) GO TO 75
      SQFT = 11.58499 * DBHT - 11.09724
      GO TO 76
   75 IF(DBHT .GE. 10.0) GO TO 77
      TEM = DBHT * DBHT
      SQFT = 7.76226 * DBHT +0.85289 * TEM -0.07952 * TEM * DBHT-3.45624
   76 BAST = (PRET / 80.0) * SQFT
      GO TO 80
   77 BAST = REST
   80 RETURN
      END
      SUBROUTINE GOT
C
C TO COMPUTE PRESENT VOLUMES, DISTRIBUTIONS OF AREA AND VOLUME, AND
C POTENTIAL GROWTH FROM INVENTORY DATA.
C
      COMMON ABFAG(3,15),ACBAR(5),ACSI(3,5,10),ACSP(3,5),ALLCF(3,10),AMC
     1AG(3,15),ANCUT(3,10),ARBK(5),AREA(3,10),BARSI(5,10),BFAGE(3,15),BF
     2TH(5,12),BFMRCH,CFAGE(3,15),CFBF(3,10),CMTH(5,12),COMBF(3),COMCU,C
     3UTA(5,12),CUTB(5,12),CYCL,DATE(3),DLEV(3),FINL(3),FORET(3),GRBD(3,
     45,15),GRMC(3,5,15),GROWB(3),GROWC(3),GVLBF(3),GVLCU(3),MIN,NBK,NCM
     5P,NSBK(5),NSI(3),NSUB,OPEN(5,12),POOR(3),PRET,RAGE(3,10),RINT,ROTA
     6,SARETY(5,20),SARSP(3),SBARB,SBARE,SBARG,SBF(3),SHELT(3),SHWD(3),S
     7LAND,SLVG(5,12),SMC(3),SMSP(3),STYP(20),SUBBF(3,10),SUBCF(3,10),SU
     8MCF(3),THIN(3),TMBR,TMPO,TYPNM(20),DELAY(3),ACFNL(3,5,15),ACRGN(3,
     95,15),TIME,PDCFR(5,12),PDCFN(5,12),OPCU(3),FNCU(3),CUINT(3),ACINT(
     13),FNBD(3),BFINT(3),OPBD(3),TEM,MNK,KNO,FCTR(2),PROD(2),KAK,VDM(2)
     2,ADJ(3),ALOWC(3),ALWBF(3),BOMAI(3),CUMAI(3),PAIBO(3),PAICU(3),DBHO
     3,DENO,REST,DBHT,BAST,NWGP,HELP(5,12),BA(2)
C
C VARIABLES LISTED IN DIMENSION AFTER TVL(I) ARE NEEDED ONLY IF ANY
C INVENTORY RECORDS HAVE ACRE = 0.0.
C
      DIMENSION BFBLK(5),BFSP(3,5),BFTB(5,12),CFMER(5),CFTB(5,12),CMSP(3
     1,5),CMTB(5,12),DBH(2),DEN(2),FBA(2),FBD(2),FDM(2),FDN(2),FHT(2),FM
     2C(2),FVL(2),HT(2),PTBF(3,5,15),PTCU(3,5,15),PTMC(3,5,15),SPLT(5,12
     33),TCF(5),TCSP(3,5),UNCML(5,12),AGE(2),STC(3),BAS(2),TOT(2),CM(2),B
     4FM(2),TBA(2),TBD(2),TDM(2),TCM(2),TVL(2),PAFN(3,5,15),PARG(3,5,15)
     5,PSPLT(5,12),PAS1(3,5,10),PBFT(5,12),PBRSI(5,10),PCMT(5,12),PCTA(5
     6,12),PCTB(5,12),PGBD(3,5,15),PGMC(3,5,15),POPN(5,12),PPBF(3,5,15),
     7PPCR(5,12),PPFN(5,12),PPMC(3,5,15),PPTC(3,5,15),PS(3,5,10),PSLV(5,
     812),PUNC(5,12),TPB(3,5),PARTY(5,20),PABR(5),PASP(3,5),PHLP(5,12)
C
C INITIALIZE VARIABLES FIRST DEFINED IN THIS SUBROUTINE.
C
      SBDF = 0.0
      SCFM = 0.0
      SSPT = 0.0
      STCF = 0.0
      SUNC = 0.0
      TMPO = 0.0
      DO 2 I=1,3
      STC(I) = 0.0
      DO 2 J=1,5
      BFSP(I,J) = 0.0
      CMSP(I,J) = 0.0
      PASP(I,J) = 0.0
      TCSP(I,J) = 0.0
      TPB(I,J) = 0.0
      DO 2 K=1,15
      PAFN(I,J,K) = 0.0
      PARG(I,J,K) = 0.0
      PGBD(I,J,K) = 0.0
      PGMC(I,J,K) = 0.0
      PPBF(I,J,K) = 0.0
      PPMC(I,J,K) = 0.0
      PPTC(I,J,K) = 0.0
      PTBF(I,J,K) = 0.0
      PTCU(I,J,K) = 0.0
      PTMC(I,J,K) = 0.0
    2 CONTINUE
      DO 4 I=1,5
      BFBLK(I) = 0.0
      CFMER(I) = 0.0
      PABR(I) = 0.0
      TCF(I) = 0.0
      DO 4 J=1,12
      BFTB(I,J) = 0.0
      CFTB(I,J) = 0.0
      CMTB(I,J) = 0.0
      PBFT(I,J) = 0.0
      PCMT(I,J) = 0.0
      PCTA(I,J) = 0.0
      PCTB(I,J) = 0.0
      PHLP(I,J) = 0.0
      POPN(I,J) = 0.0
      PPCR(I,J) = 0.0
      PPFN(I,J) = 0.0
      PSLV(I,J) = 0.0
      PSPLT(I,J) = 0.0
      PUNC(I,J) = 0.0
      SPLT(I,J) = 0.0
      UNCML(I,J) = 0.0
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    4 CONTINUE
      DO 5 I=1,3
      DO 5 J=1,5
      DO 5 K=1,10
      PASI(I,J,K) = 0.0
    5 PS(I,J,K) = 0.0
      DO 6 I=1,5
      DO 6 J=1,10
    6 PBRSI(I,J) = 0.0
C
C CREATE DUPLICATE RECORD OF AREAS COMPUTED BY PREVIOUS ROUTINE.
C
      DO 8 I=1,NWGP
      DO 8 J=1,NBK
    8 PASP(I,J) = ACSP(I,J)
      DO 9 I=1,NBK
      DO 9 J=1,20
    9 PARTY(I,J) = SARETY(I,J)
C
C INITIALIZE VARIABLES RECOMPUTED FOR EACH INVENTORY RECORD.
C
   10 DO 11 I=1,2
      BAS(I) = 0.0
      BFM(I) = 0.0
      CM(I) = 0.0
      FBA(I) = 0.0
      FBC(I) = 0.0
      FBM(I) = 0.0
      FCN(I) = 0.0
      FHT(I) = 0.0
      FMC(I) = 0.0
      FVL(I) = 0.0
      TBA(I) = 0.0
      TBC(I) = 0.0
      TCM(I) = 0.0
      TDM(I) = 0.0
      TVL(I) = 0.0
   11 TOT(I) = 0.0
      BAUS = 0.0
      BCUS = 0.0
      BFVOL = 0.0
      CFVOL = 0.0
      CMUS = 0.0
      DMUS = 0.0
      DNUS = 0.0
      FTBD = 0.0
      FTCM = 0.0
      HTUS = 0.0
      STOR1 = 0.0
      STOR2 = 0.0
      TEM = MIN
      TMBD = 0.0
      TMCF = 0.0
      VLUS = 0.0
C
C READ INVENTORY DATA, ONE RECORD AT A TIME.
C LOGICAL UNIT 4 HOLDS THE INVENTORY TAPE.
C
      READ (4,12) IBK,KOMP,ISUB,QTR1,QTR2,SECT,TOWN,RANG,SITE,STRY,NTYP,
     1WORK,DBH(1),HT(1),DEN(1),AGE(1),DBH(2),HT(2),DEN(2),AGE(2),ACRE,WH
     2EN
   12 FORMAT (I2,I4,I3,3A3,2A4,F4.0,F2.0,I3,F3.0,F4.1,F3.0,F5.0,F4.0,F4.
     11,F3.0,F5.0,F4.0,F5.1,F5.0)
C
C STOP VOLUME COMPUTATIONS IF ALL INVENTORY RECORDS READ.
C
      IF(IBK .EQ. 0 .OR. IBK .GT. NBK) GO TO 150
C
C CONTINUE COMPUTATIONS IF ALL RECORDS NOT READ.
C
      PARTY(IBK,NTYP) = PARTY(IBK,NTYP) - ACRE
      STOR1 = HT(1)
      STOR2 = HT(2)
      JS = (AGE(1) + 9.0) * 0.1
      IF(STRY .GT. 0.0) JS = (AGE(2) + 9.0) * 0.1
      IF(JS .GT. 15) JS = 15
C
C COUNT TOTAL NUMBER OF INVENTORY RECORDS BY BLOCK AND TYPE.
C
      SPLT(IBK,NTYP) = SPLT(IBK,NTYP) + 1.0
      IF(ACRE .GT. 0.0) GO TO 16
      PSPLT(IBK,NTYP) = PSPLT(IBK,NTYP) + 1.0
   16 ISI = (SITE + 4.0) * 0.1
      IF(ISI .LT. 1) GO TO 10
      IF(NTYP .LE. 10) GO TO 18
      IF(ACRE .EQ. 0.0) GO TO 17
      BARSI(IBK,ISI) = BARSI(IBK,ISI) + ACRE
      GO TO 10
   17 PBRSI(IBK,ISI) = PBRSI(IBK,ISI) + 1.0
      GO TO 10
   18 IF(NTYP .GT. 0 .AND. NTYP .LT. 6) KAK = 1
      IF(NTYP .GT. 5 .AND. NTYP .LT. 11) KAK = 2
      IF(ACRE .EQ. 0.0) GO TO 19
      ACSI(KAK,IBK,ISI) = ACSI(KAK,IBK,ISI) + ACRE
      PASP(KAK,IBK) = PASP(KAK,IBK) - ACRE
      GO TO 20
   19 PS(KAK,IBK,ISI) = PS(KAK,IBK,ISI) + 1.0
   20 IF(SITE .GE. PCOR(KAK)) GO TO 22
      IF(ACRE .EQ. 0.0) GO TO 21
      UNCML(IBK,NTYP) = UNCML(IBK,NTYP) + ACRE
      GO TO 10
   21 PUNC(IBK,NTYP) = PUNC(IBK,NTYP) + 1.0
      GO TO 10
   22 IF(DBH(1) .GT. 0.0) GO TO 26
C
C TEST FOR NONCOMMERCIAL THINNING IN VERY YOUNG STANDS.
C
      IF(WORK .NE. 2.0) GO TO 10
      IF(ACRE .EQ. 0.0) GO TO 25
      HELP(IBK,NTYP) = HELP(IBK,NTYP) + ACRE
      GO TO 10
   25 PHELP(IBK,NTYP) = PHELP(IBK,NTYP) + 1.0
      GO TO 10
C
C COMPUTE BASAL AREAS AND VOLUMES PER ACRE.
C
   26 DO 29 I=1,2
      BAS(I) = 0.005454542 * DBH(I) * DBH(I) * DEN(I)
      IF(DBH(I) .LT. 3.0) GO TO 27
      IF(AGE(I) .LT. TEM) GO TO 29
      IF(NTYP .GT. 5) GO TO 28
      D2H = DBH(I) * DBH(I) * HT(I)
      IF(D2H .GT. 6000.0) GO TO 27
      TOT(I) = 10.00225 * D2H - 0.16074 * BAS(I) + .6371(I) * TEN(I)
      GO TO 29
   27 TOT(I) = 10.00247 * D2H + 0.5.140 * BAS(I) - 1.40284 * DEN(I)
      GO TO 29
   28 TOT(I) = 0.50 * BAS(I) * HT(I) + 10.36
   29 CONTINUE
C
C IF WORK CODES FOR THINNING, VERIFY THAT IT CAN BE DONE.
C
      IF(WORK .EQ. 2.0) GO TO 30
      IF(WORK .EQ. 6.0) GO TO 31
      GO TO 38
   30 K = 1
      GO TO 32
   31 K = 2
   32 IF(DBH(K) .LT. 2.0) GO TO 38
      IF(DBH(K) .GT. 5.0) GO TO 33
      LEVL = 80.0 * BAS(K) / (11.58495 * DBH(K) - 11.09724)
      TMPY = THIN(KAK)
      GO TO 36
   33 IF(DBH(K) .GE. 10.0) GO TO 34
      TEM = DBH(K) * DBH(K)
      LEVL = 80.0 * BAS(K) / (7.76226 * DBH(K) + 0.85289 * TEM - 0.07952
     1* TEM * DBH(K) - 3.45624)
      GO TO 35
   34 LEVL = BAS(K)
   35 TMPY = DLEV(KAK)
   36 IF(WORK .EQ. 6.0) GO TO 37
      IF(LEVL .LE. TMPY) WORK = 0.0
      GO TO 38
   37 IF(LEVL .LE. TMPY) WORK = 5.0
   38 IF(TOT(1) .EQ. 0.0) GO TO 48
C
C CONVERT TOTAL CU. FT. TO OTHER UNITS.
C
      IF(DBH(1) .LT. 5.0) GO TO 40
      KNO = 2
      BA(1) = BAS(1)
      BA(2) = BAS(2)
      VOM(1) = DBH(1)
      VOM(2) = DBH(2)
      CALL VOLS
      DO 39 I=1,7
      BFM(I) = TOT(I) * PROD(I) * 0.001
   39 CM(I) = TOT(I) * FCTR(I) * 0.01
   40 DO 41 I=1,2
   41 TOT(I) = TOT(I) * 0.01
C
C ADD VOLUMES TO APPROPRIATE TOTALS.
C
      TMCF = CM(1) + CM(2)
      TMBD = BFM(1) + BFM(2)
      IF(ACRE .EQ. 0.0) GO TO 45
      PTCU(KAK,IBK,JS) = PTCU(KAK,IBK,JS) + (TOT(1) + TOT(2)) * ACRE
      PTMC(KAK,IBK,JS) = PTMC(KAK,IBK,JS) + (TMCF * ACRE)
      IF(TMBD .LT. BFMRCH) GO TO 48
      PTBF(KAK,IBK,JS) = PTBF(KAK,IBK,JS) + (TMBD * ACRE)
      GO TO 48
   45 PPTC(KAK,IBK,JS) = PPTC(KAK,IBK,JS) + TOT(1) + TOT(2)
      PPMC(KAK,IBK,JS) = PPMC(KAK,IBK,JS) + TMCF
      IF(TMBD .LT. BFMRCH) GO TO 48
      PPBF(KAK,IBK,JS) = PPBF(KAK,IBK,JS) + TMBD
C
C COMPUTE GROWTH FOR NEXT PERIOD BY WORKING GROUP, BLOCK, AND AGE CLASS.
C
   48 IF(WORK .NE. 3.0) GO TO 51
      IF(BFM(1) .LT. COMBF(KAK)) GO TO 10
      IF(ACRE .EQ. 0.0) GO TO 50
      SLVG(IBK,NTYP) = SLVG(IBK,NTYP) + (BFM(1) * ACRE)
      GO TO 10
   50 PSLV(IBK,NTYP) = PSLV(IBK,NTYP) + BFM(1)
      GO TO 10
   51 TMDY = AGE(1) + TIME
      TEM = MIN
      IF(TMDY .LT. TEM) GO TO 66
      SBAS = BAS(1) + BAS(2)
      IF(SBAS .EQ. 0.0) GO TO 66
      J = TIME / RINT
      DO 62 K=1,J
      IF(KAK .EQ. 2) GO TO 52
      DO 55 I=1,2
      TMDY = AGE(I) + TIME
      IF(TMDY .LT. TEM) GO TO 55
      FBM(I) = 0.8851[illegible] * DBH(I) * 1.2[illegible] * A[illegible](HT(I)) * [illegible] * DB
     1H(I) * SITE + 62.37174 / SBAS - 1.5[illegible]
      IF(DBH(I) .GE. 10.0) GO TO 52
      FBM(I) = 0.[illegible] + 0.[illegible] * [illegible] + [illegible] * DBH(I) * DBH(I) +
     10.[illegible] * SBAS * SBAS - [illegible] * DBH(I) * SBAS
      IF(FBM(I) .LT. 0.0) FBM(I) = 0.0
      FBM(I) = [illegible](I) * (1.[illegible] + A[illegible])
      MNK = FBM(I) + 0.5
      FBM(I) = MNK
      GO TO 53
   52 FBM(I) = FBM(I)
   53 FBA(I) = 0.005454542 * FBM(I) * FBM(I) * FBM(I)
      FHT(I) = 15.43621 + 1.107 * HT(I) - [illegible] * A[illegible]    3[illegible] /
     1SITE - 0.32447 * SITE * SBAS / 1[illegible]
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      D2H = FDM(I) * FDM(I) * FHT(I)
      IF(D2H .GT. 6000.0) GO TO 54
      FVL(I) = (0.00225 * D2H - 0.00074 * FBA(I) + 0.03711) * FDM(I)
      GO TO 55
   54 FVL(I) = (0.00247 * D2H + 0.00130 * FBA(I) - 1.40286) * FDM(I)
   55 CONTINUE
      GO TO 60
   56 DO 59 I=1,2
      TMDY = AGE(I) + TIME
      IF(TMDY .LT. TEM) GO TO 59
      FDM(I) = 0.2631 + 0.95287 * DBH(I) + 0.0016 * DBH(I) * SITE + 16.4
     16662 / SBAS
      IF(DBH(I) .GE. 10.0) GO TO 57
      FDN(I) = 0.05285 - 0.01346 * DBH(I) + 0.00226 * DBH(I) * DBH(I) +
     10.00000066 * SBAS * SBAS - 0.0001931 * DBH(I) * SBAS
      IF(FDN(I) .LT. 0.0) FDN(I) = 0.0
      FDN(I) = DEN(I) * (1.0 - FDN(I))
      MNK = FDN(I) + 0.5
      FDN(I) = MNK
      GO TO 58
   57 FDN(I) = DEN(I)
   58 FBA(I) = 0.0054542 * FDM(I) * FDM(I) * FDN(I)
      FHT(I) = 14.57349 + 1.101 * HT(I) - 0.09654 * AGE(I) - 333.37172 /
     1SITE - 0.04321 * SITE * SBAS / 100.0
      FVL(I) = 0.50 * FBA(I) * FHT(I) + 16.96
   59 CONTINUE
   60 IF(J .EQ. 1) GO TO 62
      DO 61 I=1,2
      AGE(I) = AGE(I) + RINT
      DBH(I) = FDM(I)
      DEN(I) = FDN(I)
      HT(I) = FHT(I)
   61 CONTINUE
      SBAS = FBA(1) + FBA(2)
   62 CONTINUE
C
C CONVERT TOTAL CU. FT. TO OTHER UNITS.
C
      IF(FDM(1) .LT. 5.0) GO TO 66
      KNO = 2
      BA(1) = FBA(1)
      BA(2) = FBA(2)
      VDM(1) = FDM(1)
      VDM(2) = FDM(2)
      CALL VOLS
      DO 65 I=1,2
      FBD(I) = FVL(I) * PROD(I) * 0.001
      FMC(I) = FVL(I) * FCTR(I) * 0.01
   65 CONTINUE
C
C ADD PERIODIC GROWTH IF NO WORK IS PLANNED DURING NEXT PERIOD.
C
   66 IF(WORK .GT. 1.0) GO TO 70
      IF(ACRE .EQ. 0.0) GO TO 67
      GRBD(KAK,IBK,JS) = GRBD(KAK,IBK,JS) + (FBD(1)+FBD(2)-TMBD) * ACRE
      GRMC(KAK,IBK,JS) = GRMC(KAK,IBK,JS) + (FMC(1)+FMC(2)-TMCF) * ACRE
      GO TO 10
   67 PGBD(KAK,IBK,JS) = PGBD(KAK,IBK,JS) + FBD(1) + FBD(2) - TMBD
      PGMC(KAK,IBK,JS) = PGMC(KAK,IBK,JS) + FMC(1) + FMC(2) - TMCF
      GO TO 10
C
C COMPUTE FUTURE UNTHINNED UNDERSTORY IF OVERSTORY IS REDUCED NOW.
C
   70 IF(WORK .LT. 4.0) GO TO 85
      IF(WORK .GT. 5.0) GO TO 85
      IF(DBH(2) .EQ. 0.0) GO TO 85
      IF(KAK .EQ. 2) GO TO 74
      DMUS = 0.88511 * DBH(2) + 1.29735 * ALOG10(HT(2)) + 0.00119 * DBH(
     12) * SITE + 62.37174 / BAS(2) - 1.56375
      IF(DBH(2) .GE. 10.0) GO TO 71
      DNUS = 0.00247 + 0.00124 * DBH(2) + 0.00028 * DBH(2) * DBH(2) + 0.
     100000521 * BAS(2) * BAS(2) - 0.0000905 * DBH(2) * BAS(2)
      IF(DNUS .LT. 0.0) DNUS = 0.0
      DNUS = DEN(2) * (1.0 - DNUS)
      MNK = DNUS + 0.5
      DNUS = MNK
      GO TO 72
   71 DNUS = DEN(2)
   72 BAUS = 0.0054542 * DMUS * DMUS * DNUS
      HTUS = 15.43021 + 1.107 * HT(2) - 0.08637 * AGE(2) - 304.12172 / S
     1ITE - 0.02447 * SITE * BAS(2) / 100.0
      D2H = DMUS * DMUS * HTUS
      IF(D2H .GT. 6000.0) GO TO 73
      VLUS = (0.00225 * D2H - 0.00074 * BAUS + 0.03711) * DNUS
      GO TO 77
   73 VLUS = (0.00247 * D2H + 0.00130 * BAUS - 1.40286) * DNUS
      GO TO 77
   74 DMUS = 0.2631 + 0.95287 * DBH(2) + 0.0016 * DBH(2) * SITE + 16.466
     162 / BAS(2)
      IF(DBH(2) .GE. 10.0) GO TO 75
      DNUS = 0.05285 - 0.01346 * DBH(2) + 0.00226 * DBH(2) * DBH(2) + 0.
     100000066 * BAS(2) * BAS(2) - 0.0001931 * DBH(2) * BAS(2)
      IF(DNUS .LT. 0.0) DNUS = 0.0
      DNUS = DEN(2) * (1.0 - DNUS)
      MNK = DNUS + 0.5
      DNUS = MNK
      GO TO 76
   75 DNUS = DEN(2)
   76 BAUS = 0.0054542 * DMUS * DMUS * DNUS
      HTUS = 14.57349 + 1.101 * HT(2) - 0.09654 * AGE(2) - 333.37172 / S
     1ITE - 0.04321 * SITE * BAS(2) / 100.0
      VLUS = 0.50 * BAUS * HTUS + 16.96
   77 IF(DMUS .LT. 5.0) GO TO 85
      KNO = 1
      BA(1) = BAUS
      VDM(1) = DMUS
      CALL VOLS
      BDUS = VLUS * PROD(1) * 0.001
      CMUS = VLUS * FCTR(1) * 0.01
C
C IF CMIN > POTENTIAL WORK LOAD FOR NEXT PERIOD, CREDIT FUTURE CUTS
C WITH HALF PERIODIC GROWTH OBTAINED IF NOT CUT.
C INCLUDE STAND, YEAR ROTATION AGE IN POTENTIAL REGENERATION CUTS
C AVAILABLE IF WORK INDEX.
C
      IF(WORK .GT. 3.0) GO TO 45
      IF(WORK .LT. 4.0) GO TO 45
C
C COMPUTE GROWTH AND YIELD OF STANDS TO BE REGENERATED IN NEXT PERIOD.
C
      TEM = AMAX1(RAK) * TIME + 0.01
      DMY = SHELT(KAK)
      TMPY = (FBM(1) + BFM(1)) * 0.5
      IF(TMPY .LT. DMY) DMY = TMPY
      IF(ACRE .EQ. 0.0) GO TO 86
      GRBD(KAK,IBK,JS) = GRBD(KAK,IBK,JS) + (FBD(2) + BDUS - BFM(2) - BF
     1M(2) + FBD(1) - BFM(1) + DMY * TEM) * 0.5 * ACRE
      ACRGN(KAK,IBK,JS) = ACRGN(KAK,IBK,JS) + ACRE
      GO TO 87
   86 PGBD(KAK,IBK,JS) = PGBD(KAK,IBK,JS) + (FBD(2) + BDUS - BFM(2) - BF
     1M(2) + FBD(1) - BFM(1) + DMY * TEM) * 0.5
      PARG(KAK,IBK,JS) = PARG(KAK,IBK,JS) + 1.0
   87 TEM = AMAX1(RAK) * TIME * 0.01
      DMY = SHELT(KAK)
      TMPY = (FMC(1) + CM(1)) * 0.5
      IF(TMPY .LT. DMY) DMY = TMPY
      IF(ACRE .EQ. 0.0) GO TO 88
      GRMC(KAK,IBK,JS) = GRMC(KAK,IBK,JS) + (FMC(2) + CMUS - CM(2) - CM(
     12) + FMC(1) - CM(1) + DMY * TEM) * 0.5 * ACRE
      GO TO 89
   88 PGMC(KAK,IBK,JS) = PGMC(KAK,IBK,JS) + (FMC(2) + CMUS - CM(2) - CM(
     12) + FMC(1) - CM(1) + DMY * TEM) * 0.5
   89 BFVOL = (BFM(1) + FBD(1)) * 0.5 - SHELT(KAK)
      CFVOL = (CM(1) + FMC(1)) * 0.5 - SHWD(KAK)
      IF(BFVOL .LT. COMBF(KAK)) GO TO 91
      ADD = BFVOL * (0.63821 + 28.99151 / DBH(1))
      ADD = CFVOL - ADD
      IF(ADD .LT. COMCU) ADD = 0.0
      IF(ACRE .EQ. 0.0) GO TO 90
      CUTA(IBK,NTYP) = CUTA(IBK,NTYP) + (BFVOL * ACRE)
      PCCFR(IBK,NTYP) = PCCFR(IBK,NTYP) + (ADD * ACRE)
      GO TO 10
   90 PCTA(IBK,NTYP) = PCTA(IBK,NTYP) + BFVOL
      PPCFR(IBK,NTYP) = PPCFR(IBK,NTYP) + ADD
      GO TO 10
   91 IF(CFVOL .LT. COMCU) GO TO 10
      IF(ACRE .EQ. 0.0) GO TO 92
      PCCFR(IBK,NTYP) = PDCFR(IBK,NTYP) + (CFVOL * ACRE)
      GO TO 10
   92 PPCR(IBK,NTYP) = PPCR(IBK,NTYP) + CFVOL
      GO TO 10
C
C COMPUTE GROWTH AND YIELD OF STANDS TO LOSE OVERSTORY IN NEXT PERIOD.
C
   95 IF(ACRE .EQ. 0.0) GO TO 96
      GRBD(KAK,IBK,JS) = GRBD(KAK,IBK,JS)+((FBD(1) - BFM(1)) * 0.5)*ACRE
      GRMC(KAK,IBK,JS) = GRMC(KAK,IBK,JS)+((FMC(1) - CM(1)) * 0.5)*ACRE
      ACFNL(KAK,IBK,JS) = ACFNL(KAK,IBK,JS) + ACRE
      GO TO 97
   96 PGBD(KAK,IBK,JS) = PGBD(KAK,IBK,JS) + (FBD(1) - BFM(1)) * 0.5
      PGMC(KAK,IBK,JS) = PGMC(KAK,IBK,JS) + (FMC(1) - CM(1)) * 0.5
      PAFN(KAK,IBK,JS) = PAFN(KAK,IBK,JS) + 1.0
   97 BFVOL = (BFM(1) + FBD(1)) * 0.5
      CFVOL = (CM(1) + FMC(1)) * 0.5
      IF(BFVOL .LT. COMBF(KAK)) GO TO 99
      ADD = BFVOL * (0.63821 + 28.99151 / DBH(1))
      ADD = CFVOL - ADD
      IF(ADD .LT. COMCU) ADD = 0.0
      IF(ACRE .EQ. 0.0) GO TO 98
      CUTB(IBK,NTYP) = CUTB(IBK,NTYP) + BFVOL * ACRE
      PCCFN(IBK,NTYP) = PDCFN(IBK,NTYP) + (ADD * ACRE)
      GO TO 101
   98 PCTB(IBK,NTYP) = PCTB(IBK,NTYP) + BFVOL
      PPFN(IBK,NTYP) = PPFN(IBK,NTYP) + ADD
      GO TO 101
   99 IF(CFVOL .LT. COMCU) GO TO 101
      IF(ACRE .EQ. 0.0) GO TO 100
      PDCFN(IBK,NTYP) = PDCFN(IBK,NTYP) + CFVOL * ACRE
      GO TO 101
  100 PPFN(IBK,NTYP) = PPFN(IBK,NTYP) + CFVOL
  101 IF(WORK .GT. 5.0) GO TO 105
      IF(ACRE .EQ. 0.0) GO TO 102
      GRBD(KAK,IBK,JS) = GRBD(KAK,IBK,JS) + (FBD(2) - BFM(2) + BDUS - BF
     1M(2)) * 0.5 * ACRE
      GRMC(KAK,IBK,JS) = GRMC(KAK,IBK,JS) + (FMC(2) - CM(2) + CMUS - CM(
     12)) * 0.5 * ACRE
      GO TO 10
  102 PGBD(KAK,IBK,JS) = PGBD(KAK,IBK,JS) + (FBD(2) - BFM(2) + BDUS - BF
     1M(2)) * 0.5
      PGMC(KAK,IBK,JS) = PGMC(KAK,IBK,JS) + (FMC(2) - CM(2) + CMUS - CM(
     12)) * 0.5
      GO TO 10
  105 HT(1) = STOR1
      HT(2) = STOR2
C
C GET VOLUME IF THINNED NOW AND IF THINNED IN TIME YEARS.
C
      K = 1
      IF(WORK .EQ. 6.0) K = 2
      DO 110 I=1,2
      REST = DLEV(KAK)
      IF(I .EQ. 2) GO TO 106
      IF(DBH(K) .EQ. 0.0) GO TO 110
      IF(DBH(K) .LT. 6.0) REST = THIN(KAK)
      DBHO = DBH(K)
      DENO = DEN(K)
      GO TO 107
  106 IF(FDM(K) .EQ. 0.0) GO TO 110
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      IF(FEMAK(K) .LT. 0. ) RMST = THINEKAK1
      TMST = F_MI(K)
      PMST = FT(K)
  107 ALL CUTS
      TBA(1) = RMST
      TCM(1) = PMST
      IF(I .EQ. 1) SAVE = PMST
      IF(I .EQ. 2) HT(K) = FHT(K)
      IF(KAK .EQ. 2) GO TO 109
      FT(K) = HT(K) + 7.66833 - 3.82286 * ALOG10(SAVE)
      TEM = TBA(1) / (0.0054542 * TCM(1) * TCM(1))
      D2H = TCM(1) * HT(K)
      IF(D2H .LT. 6000.0) GO TO 108
      FVL(1) = (0.00225 * D2H - 0.00074 * TBA(1) * 0.03711) * TEM
      GO TO 110
  108 FVL(1) = (0.00247 * D2H + 0.00130 * TBA(1) - 1.40286) * TEM
      GO TO 110
  109 FVL(1) = 0.50 * TBA(1) * HT(K) + 16.96
  110 CONTINUE

C CONVERT TOTAL CU. FT. TO OTHER UNITS.

      IF(TCM(2) .LT. 5.0) GO TO 120
      KNO = 2
      BA(1) = TBA(1)
      BA(2) = TBA(2)
      VCM(1) = TCM(1)
      VCM(2) = TCM(2)
      CALL VOLS
      DO 117 I=1,2
      IF(FVL(I) .EQ. 0.0) GO TO 117
      TBC(I) = FVL(I) * PROD(I) * 0.001
      TCM(I) = FVL(I) * FCTR(I) * 0.01
  117 CONTINUE

C SET STATUS AT END OF PERIOD OF A PLOT THINNED AT START OF PERIOD.

  120 I = TIME / RINT
      HT(1) = STOR1
      IF(K .EQ. 2) HT(1) = STOR2
      IF(KAK .EQ. 2) GO TO 128
      DO 125 I=1,2
      IF(TBA(I) .LE. 0.01) GO TO 125
      HT(I) = HT(I) + 7.64833 - 3.82286 * ALOG10(SAVE)
      BBM(I) = 1.0097*TCM(I)+0.0096*SITE-1.5766*ALOG10(TBA(I))+3.3021
      FHT(I) = 14.43021 + 1.107 * HT(I) - 0.08637 * AGE(K) - 304.12172 /
     1SITE - 0.02447 * SITE * TBA(I) / 100.0
      MNK = (TBA(I) / (0.0054542 * TCM(I) * TCM(I))) + 0.5
      IF(TCM(1) .LT. 10.01) GO TO 121
      FDN(I) = MNK
      GO TO 122
  121 FDN(I) = 0.00247 + 0.00124 * TCM(I) + 0.00028 * TCM(I) * TCM(I) +
     10.0000521 * TBA(I) * TBA(I) - 0.0000905 * TCM(I) * TBA(I)
      IF(FDN(I) .LT. 0.0) FDN(I) = 0.0
      TEM = MNK
      NKM = TEM * (1.0 - FDN(I)) + 0.5
      FDN(I) = NKM
  122 FBA(I) = FDN(I) * 0.0054542 * FDM(I) * FDM(I)
      TCM(I) = FCM(I)
      TBA(I) = FBA(I)
      HT(I) = FHT(I)
      AGE(K) = AGE(K) + RINT
  125 CONTINUE
      D2H = FDM(1) * FDM(1) * FHT(1)
      IF(D2H .GT. 6000.0) GO TO 127
      FVL(1) = (0.00225 * D2H - 0.00074 * FBA(1) + 0.03711) * FDN(1)
      GO TO 132
  127 FVL(1) = (0.00247 * D2H + 0.00130 * FBA(1) - 1.40286) * FDN(1)
      GO TO 132
  128 DO 131 I=1,2
      IF(TBA(1) .LE. 0.01) GO TO 131
      BBM(1) = 1.0222*TCM(1)+0.0151*SITE-1.2417*ALOG10(TBA(1))+2.145
      FHT(1) = 14.57345 + 1.101 * HT(1) - 0.09654 * AGE(K) - 333.37172 /
     1SITE - 0.04321 * SITE * TBA(1) / 100.0
      IF(TCM(1) .LT. 10.01) GO TO 129
      MNK = (TBA(1) / (0.0054542 * TCM(1) * TCM(1))) + 0.5
      FDN(1) = MNK
      GO TO 130
  129 TEM = 0.05285 - 0.01346 * TCM(1) + 0.00226 * TCM(1) * TCM(1) + 0.0
     1000066 * TBA(1) * TBA(1) - 0.0001931 * TCM(1) * TBA(1)
      IF(TEM .LT. 0.0) TEM = 0.0
      MNK = FDN(1) * (1.0 - TEM) + 0.5
      FDN(1) = MNK
  130 FBA(1) = FDN(1) * 0.0054542 * FDM(1) * FDM(1)
      TCM(1) = FDM(1)
      TBA(1) = FBA(1)
      HT(1) = FHT(1)
      AGE(K) = AGE(K) + RINT
  131 CONTINUE
      FVL(1) = 0.50 * FBA(1) * FHT(1) + 16.96
  132 IF(FCM(1) .LT. 5.0) GO TO 134

C
C CONVERT TOTAL CU. FT. TO OTHER UNITS.
C
      KNO = 1
      BA(1) = FBA(1)
      VCM(1) = FDM(1)
      CALL VOLS
      FTBO = FVL(1) * PROD(1) * 0.001
      FTCM = FVL(1) * FCTR(1) * 0.01
      IF(ACRE .EQ. 0.0) GO TO 133
      GRBD(KAK,IBK,JS) = GRBD(KAK,IBK,JS) + (FBD(K)   BFM(K) + FTBO - TB
     1(1)) * 0.5 * ACRE
      GRMC(KAK,IBK,JS) = GRMC(KAK,IBK,JS) + (FMC(K) - CM(K) + FTCM - TCM
     1(1)) * 0.5 * ACRE
      GO TO 134
  133 PGBD(KAK,IBK,JS) = PGBD(KAK,IBK,JS)+(FBD(K) BFM(K)+FTBO-TBO(1))*0.5
      PGMC(KAK,IBK,JS) =PGMC(KAK,IBK,JS)+(FMC(K)-CM(K)+FTCM-TCM(1))*0.5

C
C ASSIGN THINNINGS TO BD. FT. OR CU. FT. TOTALS, IF COMMERCIAL.
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  134 IF(   (FBD(K)   TBD(1) + BFM(K)   TBM(1)) * .
      THN   (FMC(K)   TMC(1) + CM(K)   TCM(1)) * .
      IF(IBK .LT. IMC(KAK)) GO TO 135
      X = TBM * (1.0 - EXP(-0.03 * (D2H - 1000.0)))
      X = TBM - X
      IF(KAK .LT. IMC(KAK)) GO TO 135
      IF(KAK .EQ. 1 .AND. IBK .LT. 14) GO TO 135
      PSTBD(IBK,NTYP)   PSTBD(IBK,NTYP) + (THN * XCOM)
      CMTH(IBK,NTYP)   CMTH(IBK,NTYP) + (X * XCOM)
      PSTBD(IBK,NTYP)   PSTBD(IBK,NTYP) + ACRE
      GO TO 10
  135 PSTBD(IBK,NTYP)   PSTBD(IBK,NTYP) + THN
      CMTH(IBK,NTYP)   CMTH(IBK,NTYP) + X
      PSTBD(IBK,NTYP)   PSTBD(IBK,NTYP) + 1.
      GO TO 10
  14  IF(IBK .LT.    ) GO TO 141
      IF(KAK .EQ. 1) GO TO 141
      CMTH(IBK,NTYP)   CMTH(IBK,NTYP) + (THC * ACRE)
      PSTBD(IBK,NTYP)   PSTBD(IBK,NTYP) + ACRE
      GO TO 10
  141 PSMTH(IBK,NTYP)   PSMTH(IBK,NTYP) + THC
      PSTBD(IBK,NTYP)   PSTBD(IBK,NTYP) + 1.0
      GO TO 10

C
C MARK ALL    F NON-COMMERCIAL THINNINGS.
C
  145 IF(ALRE .EQ. 0.0) GO TO 146
      HELP(IBK,NTYP)   HELP(IBK,NTYP) + ACRE
      GO TO 10
  146 HELP(IBK,NTYP)   HELP(IBK,NTYP) + 1.0
      GO TO 10

C THIS ENDS PROCESSING OF INDIVIDUAL INVENTORY RECORDS.

C COMPUTE TOTAL VOLUMES BY WORKING GROUP, BLOCK, AND AGE CLASS.

  150 DO 159 I=1,NWGP
      DO 159 J=1,NBK
      K = 1
      IF(I .EQ. 2) K = 6
      IF(PSPLT(J,K) .EQ. 0.0) GO TO 152
      TEM = PARTY(J,K) / PSPLT(J,K)
      DO 151 MNK=1,5
      PGBD(I,J,MNK)   PGBD(I,J,MNK) + TEM
      PGMC(I,J,MNK) = PGMC(I,J,MNK) + TEM
      PPBF(I,J,MNK)   PPBF(I,J,MNK) + TEM
      PPTC(I,J,MNK)   PPTC(I,J,MNK) + TEM
      PPMC(I,J,MNK)   PPMC(I,J,MNK) + TEM
  151 CONTINUE
  152 K = K + 1
      IF(PSPLT(J,K) .EQ. 0.0) GO TO 154
      TEM = PARTY(J,K) / PSPLT(J,K)
      DO 153 MNK=6,
      PGBD(I,J,MNK)   PGBD(I,J,MNK) + TEM
      PGMC(I,J,MNK) = PGMC(I,J,MNK) + TEM
      PPBF(I,J,MNK)   PPBF(I,J,MNK) + TEM
      PPTC(I,J,MNK)   PPTC(I,J,MNK) + TEM
      PPMC(I,J,MNK)   PPMC(I,J,MNK) + TEM
  153 CONTINUE
  154 K   K + 1
      IF(PSPLT(J,K) .EQ. 0.0) GO TO 156
      TEM = PARTY(J,K) / PSPLT(J,K)
      DO 155 MNK=11,14
      PGBD(I,J,MNK)   PGBD(I,J,MNK) + TEM
      PGMC(I,J,MNK) = PGMC(I,J,MNK) + TEM
      PPBF(I,J,MNK)   PPBF(I,J,MNK) + TEM
      PPTC(I,J,MNK)   PPTC(I,J,MNK) + TEM
      PPMC(I,J,MNK)   PPMC(I,J,MNK) + TEM
  155 CONTINUE
  156 K = K + 1
      IF(PSPLT(J,K) .EQ. 0.0) GO TO 158
      TEM   PARTY(I,K) / PSPLT(J,K)
      DO 157 MNK=11,14
      PGBD(I,J,MNK)   PGBD(I,J,MNK) + TEM
      PGMC(I,J,MNK)   PGMC(I,J,MNK) + TEM
      PPBF(I,J,MNK)   PPBF(I,J,MNK) + TEM
      PPTC(I,J,MNK)   PPTC(I,J,MNK) + TEM
      PPMC(I,J,MNK)   PPMC(I,J,MNK) + TEM
  157 CONTINUE
  158 K   K + 1
      IF(PSPLT(J,K) .EQ. 0.0) GO TO 159
      TEM = PARTY(J,K) / PSPLT(J,K)
      PGBD(I,J,15)   PGBD(I,J,15) + TEM
      PGMC(I,J,15)   PGMC(I,J,15) + TEM
      PPBF(I,J,15)   PPBF(I,J,15) + TEM
      PPTC(I,J,15)   PPTC(I,J,15) + TEM
      PPMC(I,J,15)   PPMC(I,J,15) + TEM
  159 CONTINUE
      DO 164 I=1,NWGP
      DO 164 J=1,NBK
      DO 164 K=1,15
      GRBD(I,J,K)   PGBD(I,J,K) + PPBF(I,J,K)
      GRMC(I,J,K)   PGMC(I,J,K) + PPMC(I,J,K)
      PTBF(I,J,K)   PTBF(I,J,K) + PPBF(I,J,K)
      PTCU(I,J,K)   PTCU(I,J,K) + PPTC(I,J,K)
      PTMC(I,J,K)   PTMC(I,J,K) + PPMC(I,J,K)
  164 CONTINUE

C COMPUTE TOTAL VOLUMES BY BLOCK AND TYPE.

      DO 174 I=1,NWGP
      DO 174 J=1,NBK
      K = 1
      IF(I .EQ. 2) K = 6
      DO 173 MNK=1,5
      PTBF(I,J)   PTBF(I,J) + PTBF(I,J,MNK)
      PTCU(I,J)   PTCU(I,J) + PTCU(I,J,MNK)
  173 CMTB(I,J,K) = CMTB(I,J,K) + PTMC(I,J,MNK)
      K = K + 1
```

```
      DO 171 MNK=4,5
      BFTB(J,K) = BFTB(J,K) + PTBF(I,J,MNK)
      CFTB(J,K) = CFTB(J,K) + PTCL(I,J,MNK)
  171 CMTB(J,K) = CMTB(J,K) + PTMC(I,J,MNK)
      K = K + 1
      DO 172 MNK=6,10
      BFTB(J,K) = BFTB(J,K) + PTBF(I,J,MNK)
      CFTB(J,K) = CFTB(J,K) + PTCL(I,J,MNK)
  172 CMTB(J,K) = CMTB(J,K) + PTMC(I,J,MNK)
      K = K + 1
      DO 173 MNK=11,14
      BFTB(J,K) = BFTB(J,K) + PTBF(I,J,MNK)
      CFTB(J,K) = CFTB(J,K) + PTCL(I,J,MNK)
  173 CMTB(J,K) = CMTB(J,K) + PTMC(I,J,MNK)
      K = K + 1
      BFTB(J,K) = BFTB(J,K) + PTBF(I,J,15)
      CFTB(J,K) = CFTB(J,K) + PTCL(I,J,15)
      CMTB(J,K) = CMTB(J,K) + PTMC(I,J,15)
  174 CONTINUE
C
C COMPUTE TOTAL VOLUMES BY WORKING GROUP AND AGE CLASS.
C
      DO 180 I=1,NWGP
      DO 180 J=1,NBK
      DO 180 K=1,15
      ABFAG(I,K) = ABFAG(I,K) + BTBF(I,J,K)
  180 AMCAC(I,K) = AMCAC(I,K) + PTMC(I,J,K)
C
C CONVERT WORK TOTALS TO AREAS AND VOLUMES BY BLOCK AND TYPE.
C
      DO 185 I=1,NBK
      DO 185 J=1,12
      IF(PSPLT(I,J) .EQ. 0.0) GO TO 185
      TEM = PARTY(I,J) / PSPLT(I,J)
      PBFT(I,J) = PBFT(I,J) * TEM
      PCMT(I,J) = PCMT(I,J) * TEM
      PCTA(I,J) = PCTA(I,J) * TEM
      PCTB(I,J) = PCTB(I,J) * TEM
      PHLP(I,J) = PHLP(I,J) * TEM
      POPN(I,J) = POPN(I,J) * TEM
      PPFN(I,J) = PPFN(I,J) * TEM
      PPCR(I,J) = PPCR(I,J) * TEM
      PSLV(I,J) = PSLV(I,J) * TEM
      PUNC(I,J) = PUNC(I,J) * TEM
  185 CONTINUE
C
C COMPUTE TOTAL VOLUMES OF BLOCKS AND WORKING CIRCLE.
C
      DO 186 I=1,NBK
      DO 186 J=1,12
      BFTH(I,J) = BFTH(I,J) + PBFT(I,J)
      CMTH(I,J) = CMTH(I,J) + PCMT(I,J)
      CUTA(I,J) = CUTA(I,J) + PCTA(I,J)
      CUTB(I,J) = CUTB(I,J) + PCTB(I,J)
      HELP(I,J) = HELP(I,J) + PHLP(I,J)
      OPEN(I,J) = OPEN(I,J) + POPN(I,J)
      PCCFN(I,J) = PCCFN(I,J) + PPFN(I,J)
      PCCER(I,J) = PCCER(I,J) + PPCR(I,J)
      SLVG(I,J) = SLVG(I,J) + PSLV(I,J)
      UNCML(I,J) = UNCML(I,J) + PUNC(I,J)
  186 CONTINUE
      DO 190 I=1,NBK
      DO 190 J=1,12
      BFBLK(I) = BFBLK(I) + BFTB(I,J)
      CFMER(I) = CFMER(I) + CMTB(I,J)
      SSPT = SSPT + SPLT(I,J)
      SUNC = SUNC + UNCML(I,J)
      TMPO = TMPO + SARETY(I,J)
  190 TCF(I) = TCF(I) + CFTB(I,J)
      DO 200 I=1,NBK
      DO 200 J=1,10
  200 TMBR = SARETY(I,J) + TMBR
      DO 210 I=1,NBK
      SBDF = SBDF + BFBLK(I)
      SCFM = SCFM + CFMER(I)
  210 STCF = STCF + TCF(I)
C
C COMPUTE BLOCK VOLUMES BY WORKING GROUP.
C
      DO 220 I=1,NBK
      DO 220 J=1,5
      K = J + 5
      BFSP(1,I) = BFSP(1,I) + BFTB(I,J)
      BFSP(2,I) = BFSP(2,I) + BFTB(I,K)
      CMSP(1,I) = CMSP(1,I) + CMTB(I,J)
      CMSP(2,I) = CMSP(2,I) + CMTB(I,K)
      TCSP(1,I) = TCSP(1,I) + CFTB(I,J)
  220 TCSP(2,I) = TCSP(2,I) + CFTB(I,K)
C
C COMPUTE VOLUMES BY WORKING GROUP.
C
      DO 230 I=1,NWGP
      DO 230 J=1,NBK
      SBF(I) = SBF(I) + BFSP(I,J)
      SMC(I) = SMC(I) + CMSP(I,J)
  230 STC(I) = STC(I) + TCSP(I,J)
      DO 238 I=1,NBK
  238 PABR(I) = PARTY(I,11) + PARTY(I,12)
C
C SUM ACRES BY WORKING GROUP, BLOCK, AND SITE CLASS.
C
      DO 240 I=1,NBK
      TEM = PSPLT(I,11) + PSPLT(I,12)
      IF(TEM .EQ. 0.0) GO TO 240
      DO 239 J=1,10
      PBRS(I,J) = PBRS(I,J) * (PABR(I) / TEM)
  239 CONTINUE
  240 CONTINUE
      DO 241 I=1,NBK
      DO 241 J=1,10
  241 PARS(I,J) = PARS(I,J) + PBRS(I,J)
      DO 250 I=1,NBK
      DO 250 J=1,5
      K = J + 5
      TPB(1,I) = TPB(1,I) + PSPLT(I,J)
  250 TPB(2,I) = TPB(2,I) + PSPLT(I,K)

C COMPUTE AREAS BY WORKING GROUP, BLOCK, AND SITE CLASS.

      IF(TPB .EQ. 0.0) GO TO 299
      DO 261 I=1,NBK
      DO 261 J=1,10
      IF(TPB(1,I) .EQ. 0.0) GO TO 260
      PAS(1,I,J) = PASP(1,I) * PS(1,I,J) / TPB(1,I)
  260 IF(TPB(2,I) .EQ. 0.0) GO TO 261
      PAS(2,I,J) = PASP(2,I) * PS(2,I,J) / TPB(2,I)
  261 CONTINUE
      DO 262 I=1,NWGP
      DO 262 J=1,5
      DO 262 K=1,10
  262 ACS(I,J,K) = ACS(I,J,K) + PAS(I,J,K)

C COMPUTE AREAS BY COMBINATIONS OF WORKING GROUP, BLOCK, AND AGE.
C
      DO 271 I=1,NWGP
      DO 270 J=1,NBK
      DO 270 K=1,15
      IF(TPB(I,J) .EQ. 0.0) GO TO 270
      PAFN(I,J,K) = PASP(I,J) * PAFN(I,J,K) / TPB(I,J)
      PARG(I,J,K) = PASP(I,J) * PARG(I,J,K) / TPB(I,J)
  270 CONTINUE
  271 CONTINUE
      DO 272 I=1,NWGP
      DO 272 J=1,NBK
      DO 272 K=1,15
      ACFNL(I,J,K) = ACFNL(I,J,K) + PAFN(I,J,K)
  272 ACRGN(I,J,K) = ACRGN(I,J,K) + PARG(I,J,K)
C
C COMPUTE PERIODIC ANNUAL INCREMENT.
C
      DO 280 I=1,NWGP
      DO 280 J=1,NBK
      DO 280 K=1,15
      PAIBD(I) = PAIBD(I) + PABD(I,J,K)
      PAICU(I) = PAICU(I) + PAIC(I,J,K)
  280 CONTINUE
      DO 281 I=1,NWGP
      IF(TIME .EQ. 0.0) GO TO 281
      PAIBD(I) = PAIBD(I) / TIME
      PAICU(I) = PAICU(I) / TIME
  281 CONTINUE
C
C PRINT PAGE TYPE 7 - WORKING GROUP AND BLOCK VOLUMES.
C
  299 WRITE (6,300)
  300 FORMAT (1H1,////,60X,11HPAGE TYPE 7)
      WRITE (6,301)
  301 FORMAT (1HO,//,47X,36HVOLUMES OF BLOCKS AND WORKING CIRCLE)
      WRITE (6,302) (FORET(I),I=1,3)
  302 FORMAT (1H ,54X,3A8)
      WRITE (6,303)
  303 FORMAT (1HO,//,13X,24HTOTAL PINE WORKING GROUP,17X,26HTOTAL SPRUCE
     1 WORKING GROUP,19X,21HTOTAL VOLUME OF BLOCK)
      WRITE (6,304)
  304 FORMAT (1H ,5HBLOCK,3X,5HTOTAL,8X,6HMERCH.,11X,1HM,11X,5HTOTAL,8X,
     16HMERCH.,11X,1HM,11X,5HTOTAL,8X,6HMERCH.,11X,1HM)
      WRITE (6,305)
  305 FORMAT (1H ,1X,3HNO.,3X,7HCU. FT.,7X,7HCU. FT.,7X,7HBD. FT.,7X,7HC
     1U. FT.,7X,7HCU. FT.,7X,7HBD. FT.,7X,7HCU. FT.,7X,7HCU. FT.,7X,7HBD
     2. FT.,//)
      DO 307 I=1,NBK
      WRITE (6,306) I,TCSP(1,I),CMSP(1,I),BFSP(1,I),TCSP(2,I),CMSP(2,I),
     1BFSP(2,I),TCF(I),CFMER(I),BFBLK(I)
  306 FORMAT (1HO,1X,I2,1X,8(F11.1,3X),F11.1)
  307 CONTINUE
      WRITE (6,308) STC(1),SMC(1),SBF(1),STC(2),SMC(2),SBF(2),STCF,SCFM,
     1SBDF
  308 FORMAT (1HO,//,1X,4HSUMS,8(F11.1,3X),F11.1,//////)
      WRITE (6,309)
  309 FORMAT(1HO,10X,47HCUBIC FEET IN HUNDREDS, BOARD FEET IN THOUSANDS)
C
C PRINT PAGE TYPE 8 - TYPE AREAS AND VOLUMES.
C
      WRITE (6,319)
  319 FORMAT (1H1,//,60X,11HPAGE TYPE 8)
      WRITE (6,320)
  320 FORMAT (1HO,/,39X,52HTOTAL AREAS AND VOLUMES OF BLOCKS AND WORKING
     1 CIRCLE)
      WRITE (6,302) (FORET(I),I=1,3)
      WRITE (6,321)
  321 FORMAT (1HO,5HBLOCK,7X,4HTYPE,12X,5HTOTAL,12X,5HTOTAL,12X,6HMERCH.
     1,13X,1HM,13X,5HACRES,11X,6HNUMBER)
      WRITE (6,322)
  322 FORMAT (1H ,1X,3HNO.,9X,3HNO.,12X,5HACRES,11X,7HCU. FT.,11X,7HCU.
     1FT.,9X,7HBD. FT.,9X,8HLOW SITE,7X,10HOF RECORDS,//)
      DO 325 I=1,NBK
      DO 325 J=1,12
      WRITE (6,323) I,J,SARETY(I,J),CFTB(I,J),CMTB(I,J),BFTB(I,J),UNCML(
     1I,J),SPLT(I,J)
  323 FORMAT (1H ,1X,I2,10X,I2,9X,5(F11.1,6X),F6.0)
      IF(J .LT. 12) GO TO 325
      WRITE (6,324)
  324 FORMAT (1HO)
  325 CONTINUE
      WRITE (6,326) TMPO,STCF,SCFM,SBDF,SUNC,SSPT
  326 FORMAT (1HO,6HTOTALS,18X,5(F11.1,6X),F6.0)
      WRITE (6,309)
C
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C PRINT MANAGEMENT TYPE 2 - AREAS BY SITE INDEX CLASS.
C
      WRITE (6,320)
  320 FORMAT (1H1,////,40X,11HMANAGEMENT TYPE 2)
      WRITE (6,330)
  330 FORMAT (1H ,//,46X,40HDISTRIBUTION OF AREA BY SITE INDEX CLASS)
      WRITE (6,331) (ISITE(I),I=1,3)
      WRITE (6,341)
  341 FORMAT (1H0,//,10X,5HBLOCK,1X,11HSITE INDEX,10X,14HACRES OF PINE,
     1 1X,15HACRES OF SPRUCE,10X,16HDEFORESTED/1H ,44X,13HWORKING GROUP,
     2 11X,14HWORKING GROUP,14X,6HACRES,//)
      DO 333 I=1,NBK
      DO 333 J=1,3
      MAK = I * 10
      WRITE (6,332) I,MNK,ACSI(1,I,J),ACSI(2,I,J),BARSI(I,J)
  332 FORMAT (1H ,10X,I2,16X,I3,14X,F10.1,14X,F10.1,12X,F10.1)
      IF(MNK .LT. 100) GO TO 333
      WRITE (6,324)
  333 CONTINUE
      WRITE (6,334) SMSP(1),SMSP(2),SBARE
  334 FORMAT (1H0,//,10X,5HTOTAL,29X,F12.1,12X,F12.1,10X,F12.1)
      RETURN
      END
      SUBROUTINE GOAL
C
C TO COMPUTE GROWING STOCK NEEDED TO MEET MANAGEMENT OBJECTIVES.
C
      COMMON AREAG(3,15),ACBAR(5),ACSI(3,5,10),ACSP(3,5),ALLCF(3,10),AMC
     1AGE(3,15),ANCUT(4,10),ARRK(5),AREA(3,10),BARSI(5,10),BEAGE(3,15),BF
     2TH(5,12),BFMRCM,CFAGE(3,15),CFBF(3,10),CMTH(5,12),COMBF(3),COMCU,C
     3UTA(5,12),CUTF(5,12),CYCL,DATE(3),DLEV(3),FINL(3),FORET(3),GRBD(3,
     45,15),GRMC(3,5,15),GRCWR(3),GROWC(3),GVLPF(3),GVLCU(3),MIN,NRK,NCM
     52,NSAK(5),NSI(3),NSOR,OPEN(5,12),PCER(3),PRET,RAGE(3,10),PINT,ROTA
     6,SAKETY(5,20),SARSP(3),SBARB,SBARE,SHARG,SRF(3),SHELT(3),SHWF(3),S
     7LAND,SLVG(5,12),SMC(3),SMSP(3),STYP(20),SURBF(3,10),SUBCF(3,10),SU
     8MCF(3),THIN(3),TMBR,TMPD,TYPNM(20),DELAY(3),ACFNL(3,5,15),ACRGN(3,
     95,15),TIME,PDCFR(5,12),PDCFN(5,12),OPCU(3),FNCU(3),CUINT(3),ACINT(
     13),FNBD(3),BFINT(3),OPBD(3),TEM,MAK,KNC,ECTR(2),PROD(2),KAK,VOM(2)
     2,ACU(3),ALCWC(3),ALWBF(3),BOMAI(3),CUMAI(3),PAIBD(3),PAICU(3),DBHC
     3,DENO,REST,DBHT,BAST,NWGP,HELP(5,12),BA(2)
C
      DIMENSION ANBDF(151),ANCUV(151),BDEC(150),BDFO(150),BFS(15),CFMC(1
     150),CFMO(150),CMS(15),EQIV(10),EQVCF(10),FACCF(10),FAC(10),QUAL(10
     2),STACF(10),STDAC(10),VLBF(10),VLCU(10),PCCUT(16)
C
C ASSIGN PART OF DEFORESTED AREA TO EACH WORKING GROUP.
C
      DO 2 I=1,NBK
      TEM = ACSP(1,I) + ACSP(2,I)
      IF(TEM .EQ. 0.0) GO TO 2
      FONE = ACSP(1,I) / TEM
      FTWO = ACSP(2,I) / TEM
      DO 1 J=1,10
      ACSI(1,I,J) = ACSI(1,I,J) + BARSI(I,J) * FONE
      ACSI(2,I,J) = ACSI(2,I,J) + BARSI(I,J) * FTWO
    1 CONTINUE
    2 CONTINUE
C
C COUNT NUMBER OF SITE CLASSES FOR EACH WORKING GROUP.
C
      DO 21 I=1,NWGP
      DO 10 J=1,NBK
      IF(ACSI(I,J,10) .GT. 0.0) GO TO 15
   10 CONTINUE
      DO 11 J=1,NBK
      IF(ACSI(I,J,9) .GT. 0.0) GO TO 16
   11 CONTINUE
      DO 12 J=1,NBK
      IF(ACSI(I,J,8) .GT. 0.0) GO TO 17
   12 CONTINUE
      DO 13 J=1,NBK
      IF(ACSI(I,J,7) .GT. 0.0) GO TO 18
   13 CONTINUE
      DO 14 J=1,NBK
      IF(ACSI(I,J,6) .GT. 0.0) GO TO 19
   14 CONTINUE
      GO TO 20
   15 NSI(I) = 11.0 - PCOR(I) * 0.1
      GO TO 21
   16 NSI(I) = 10.0 - PCOR(I) * 0.1
      GO TO 21
   17 NSI(I) = 9.0 - PCOR(I) * 0.1
      GO TO 21
   18 NSI(I) = 8.0 - PCOR(I) * 0.1
      GO TO 21
   19 NSI(I) = 7.0 - PCOR(I) * 0.1
      GO TO 21
   20 NSI(I) = 3
   21 CONTINUE
      DO 25 I=1,NWGP
      DO 25 J=1,NBK
      DO 25 K=1,10
   25 SARSP(I) = SARSP(I) + ACSI(I,J,K)
C
C DO REMAINDER OF SUBROUTINE ONCE FOR EACH WORKING GROUP.
C
      DO 400 KAK=1,NWGP
      DO 35 I=1,NBK
      DO 35 J=1,10
   35 AREA(KAK,J) = AREA(KAK,J) + ACSI(KAK,I,J)
C
C ZERO VARIABLES COMMON TO ALL SITES.
C
      SACCF = 0.0
      SSTAC = 0.0
      DO 40 I=1,10
      EQIV(I) = 0.0
      EQVCF(I) = 0.0
      FACCF(I) = 0.0
      FAC(I) = 0.0
      QUAL(I) = 0.0
      STACF(I) = 0.0
      STDAC(I) = 0.0
      VLBF(I) = 0.0
      VLCU(I) = 0.0
   40 CONTINUE
C
C COMPUTE AVERAGE DBH AND VOLUME PER ACRE FOR EACH SITE CLASS IN EACH
C WORKING GROUP.
C
      NSI = NSI(KAK)
      MSI = NSI(KAK) + 0.1
      KNC = MSI + NSI(KAK) - I
      IF(KNC .GT. 1) KNC = 10
C
C ENTER FOLLOWING LOOP ONCE FOR EACH SITE CLASS IN A WORKING GROUP.
C
      DO 253 KAK=I,KNC
      QUALE(KAK) = SITE
C
C SOME INITIAL STAND CONDITIONS. AT FIRST ONLY ONE WORKING GROUP.
C FIRST AGE IS FOR SITE PCOR(KAK). ONLY USE MORE THAN ONE AGE FOR EACH
C WORKING GROUP SO NO SITE CLASS IS UNDEFINED.
C
      READ (5,45) AGE,ENE,DBHI
   45 FORMAT (3F5.1)
      IF(AGE .EQ. 0.0 .OR. AGE .LT. 0.0) GO TO 253
      IF(AGE(KAK,KAK) .EQ. AGE) GO TO 253
C
C INITIALIZE VARIABLES RECOMPUTED FOR EACH SITE CLASS.
C
      ACTEM = 0.0
      ACDHT = 0.0
      BCAI = 0.0
      BFRT = 0.0
      AFTEM = 0.0
      CBAI = 0.0
      CFMT = 0.0
      CFTEM = 0.0
      HTCUM = 0.0
      JPCFC = 0
      JPCFL = 0
      JPCRT = 0
      JCFMC = 0
      JCFML = 0
      JCFMT = 0
      DO 50 I=1,15
      BFS(I) = 0.0
   50 CMS(I) = 0.0
      DO 51 I=1,150
      BDEC(I) = 0.0
      BDFO(I) = 0.0
      CFMC(I) = 0.0
   51 CFMO(I) = 0.0
      DO 52 I=1,151
      ANBF(I) = 0.0
   52 ANCUV(I) = 0.0
      DO 53 I=1,16
   53 PCCUT(I) = 0.0
      NI = AGE0
      N = AGE0
C
C OBTAIN HTSO AND TOTAL CU. FT. PER ACRE.
C
      BASO = CFNC * 0.0054542 * DBHI * DBHI
      IF(KAK .EQ. 2) GO TO 57
      IF(AGE0 .GT. 55.0) GO TO 54
      HTSO = 0.01441 * AGE0 * SITE - 0.12162 * AGE0 - 1.50453
      GO TO 55
   54 HTSO = 0.59947 - 61.5019 / AGE0 + 0.80522 * ALOG10(SITE) + 20.5252
     1* ALOG10(SITE) / AGE0
      HTSO = 10.0 ** HTSO
   55 D2H = DBHO * DBHO * HTSO
      IF(D2H .GT. 6000.0) GO TO 56
      TOTC = (0.00225 * D2H - 0.00174 * BASO + 0.03711 * DENO
      GO TO 61
   56 TOTC = (0.00247 * D2H + 0.00135 * BASO - 1.40286) * DENO
      GO TO 61
   57 IF(AGE0 .GT. 45.0) GO TO 58
      HTSO = 3.46111 - 0.05472 * AGE0 + 0.1135 * AGE0 * SITE
      GO TO 59
   58 HTSO = 0.33401 - 33.2866 / AGE0 + 0.92341 * ALOG10(SITE) + 6.27811
     1* ALOG10(SITE) / AGE0
      HTSO = 10.0 ** HTSO
   59 TOTC = 0.50 * BASO * HTSO + 16.96
C
C CONVERT TOTAL CU. FT. TO OTHER UNITS.
C
      IF(DBHO .LT. 5.0) GO TO 74
      KNO = I
      BA(1) = BASO
      VEM(1) = DBHO
      CALL VOLS
      BDFO(N) = TOTC * PROD(1)
      CFMC(N) = TOTC * ECTR(1)
C
C COMPUTE F.M.P. AFTER INITIAL THINNING.
C
   74 REST = TPINCKAK)
      CALL CUTS
C
C ENTER LOOP FOR ALL REMAINING COMPUTATIONS AND PRINTOUT.
C
      DO 184 I=1,100
      JCENT = (DAST / (0.0054542 * DBHT * DBHT)) + .5
      DENT = JDENT
      BAST = 0.0054542 * DBHT * DBHT * DENT
      IF(KAK .EQ. 2) GO TO 94
      ACDHT = 76.4933 - 3.82234 * ALOG10(DBHT)
      HTCUM = HTCUM + ACDHT
      HTST = HTSO + ACDHT
      D2H = DBHT * DBHT * HTST
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      IF(D2H .GT. 6000.0) GO TO 80
      TOTT = 10.00225 * D2H - 0.00074 * BAST + 0.03711) * DENT
      GO TO 100
   80 TOTT = (0.00247 * D2H + 0.00130 * BAST - 1.40286) * DENT
      GO TO 100
   90 HTST = HTSC
      TOTT = 0.50 * BAST * HTST + 16.96
C
C  CONVERT TOTAL CU. FT. TO OTHER UNITS.
C
  100 IF(DBHT .LT. 5.0) GO TO 120
      KNO = 1
      BA(1) = BAST
      VOL(1) = DBHT
      CALL VOLS
      BDFT = TOTT * PROD(1)
      CFMT = TOTT * FCTR(1)
C
C  CHANGE MODE AND ROUND OFF FOR PRINTING.
C
  120 JDENC = DENO + 0.5
      JHTSC = HTSC + 0.5
      JTOTO = TOTO + 0.5
      JBASC = BASC + 0.5
      JCFMO = CFMO(N) + 0.5
      JBDFO = BDFO(N) * 0.1 + 0.5
      JBDFC = JBDFC * 10
      JDENT = DENT + 0.5
      JHTST = HTST + 0.5
      JTOTT = TOTT + 0.5
      JDENC = JDENO - JDENT
      JCFMT = CFMT + 0.5
      CFMT = JCFMT
      IF(JCFMT .GT. JCFMO) JCFMO = JCFMT
      CFMO(N) = JCFMO
      JBDFT = BDFT * 0.1 + 0.5
      JBDFT = JBDFT * 10
      BDFT = BDFT
      BDFT = BDFT * .001
      IF(JBDFT .GT. JBDFO) JBDFO = JBDFT
      BDFO(N) = JBDFO
      BDFO(N) = BDFC(N) * .001
      JBAST = BAST + 0.5
      JBASC = JBASO - JBAST
      JTOTC = JTOTO - JTOTT
      JCFMC = JCFMO - JCFMT
      IF(JCFMC .LE. 0) JCFMC = 0
      CFMC(N) = JCFMC
      JBDFC = JBDFO - JBDFT
      IF(JBDFC .LE. 0) JBDFC = 0
      BDFC(N) = JBDFC
      BDFC(N) = BDFC(N) * .001
      IF(IT .GE. 2) GO TO 139
C
C  PRINT PAGE TYPE 10 - YIELD TABLE FOR EACH WORKING GROUP AND SITE.
C
C  WRITE HEADINGS FOR YIELD TABLE.
C
      WRITE (6,129)
  129 FORMAT (1H1,//,62X,12HPAGE TYPE 10)
      WRITE (6,130) QUAL(KAK),CYCL,DLEV(KAK)
  130 FORMAT (1HC,///,28X,81HYIELDS PER ACRE OF MANAGED, EVEN-AGED STANDS
     1 BASED ON PREDETERMINED STANDARDS FOR/1H ,35X,10HSITE INDEX,F5.0,1
     2H,,F5.0,19H-YEAR CUTTING CYCLE,1H,,15H DENSITY LEVEL ,F4.0)
      IF(KAK .EQ. 2) GO TO 132
      WRITE (6,131)
  131 FORMAT (1HO,56X,20HWORKING GROUP - PINE,/)
      GO TO 134
  132 WRITE (6,133)
  133 FORMAT (1HO,55X,22HWORKING GROUP - SPRUCE,/)
  134 WRITE (6,135)
  135 FORMAT (1HO,25X,38HENTIRE STAND BEFORE AND AFTER THINNING,28X,26HP
     1ERIODIC CUT AND MORTALITY)
      WRITE (6,136)
  136 FORMAT (1HO,9X,5HSTAND,10X,5HBASAL,3X,7HAVERAGE,2X,7HAVERAGE,3X,5H
     1TOTAL,3X,9HMERCHANT-,3X,7HSAWTIMBER,9X,5HBASAL,4X,5HTOTAL,3X,9HMER
     2CHANT-,3X,9HSAWTIMBER)
      WRITE (6,137)
  137 FORMAT (1H ,10X,3HAGE,4X,5HTREES,3X,4HAREA,4X,6HD.B.H.,3X,6HHEIGHT
     1,3X,6HVOLUME,2X,11HABLE VOLUME,4X,6HVOLUME,3X,5HTREES,3X,4HAREA,3X
     2,6HVOLUME,2X,11HABLE VOLUME,4X,6HVOLUME)
      WRITE (6,138)
  138 FORMAT (1H ,8X,7H(YEARS),3X,3HNO.,2X,7HSQ. FT.,4X,3HIN.,6X,3HFT.,4
     1X,7HCU. FT.,3X,7HCU. FT.,4X,9HM BD. FT.,3X,3HNO.,2X,7HSQ. FT.,2X,7
     2HCU. FT.,3X,7HCU. FT.,4X,9HM BD. FT.)
  139 WRITE (6,140) AGEO,JDENO,JBASO,DBHO,JHTSO,JTOTO,CFMO(N),BDFO(N)
  140 FORMAT (1HO,9X,F4.0,4X,I5,2X,I4,5X,F5.1,5X,I3,4X,I5,5X,F6.0,6X,F6.
     13)
      IF(AGEC .GE. ROTA) GO TO 145
      WRITE (6,141) AGEO,JDENT,JBAST,DBHT,JHTST,JTOTT,CFMT,BDFT,JDENC,JB
     1ASC,JTOTC,CFMC(N),BDFC(N)
  141 FORMAT (1H ,9X,F4.0,4X,I5,2X,I4,5X,F5.1,5X,I3,4X,I5,5X,F6.0,6X,F6.
     13,4X,I5,3X,I3,5X,I4,5X,F5.0,8X,F5.3)
C
C  COMPUTE VALUES FOR EACH PERIOD. THIN AS SPECIFIED.
C
      IK = (CYCL / RINT
      DO 163 L=1,IK
      AGEO = AGEO + RINT
      N = AGEO
      IF(AGEO .GT. ROTA) GO TO 185
      IF(KAK .EQ. 2) GO TO 146
      DBHO = 1.0097*DBHT + 0.0094*SITE - 1.5766*ALOG10(BAST) + 3.3021
      GO TO 147
  146 DBHO = 1.0222*DBHT + 0.0151*SITE - 1.2417*ALOG10(BAST) + 2.1450
  147 MNK = DBHO * 10.0 + 0.5
      DBHO = MNK
      DBHO = DBHO * 0.1
C
C  REDUCE FUTURE DENSITY BY AMOUNT OF PREDICTED MORTALITY.
C
      IF(DBHT .GE. 10.0) GO TO 152
      IF(KAK .EQ. 2) GO TO 149
      TOTT = (0.00247 * D2H + 0.00134 * BAST + 0.00628 * DBHT * DBHT + 0.000085
     1* BAST * BAST - 0.00009* DBHT * BAST
      T = TOTT
      GO TO 150
  149 TOTT = (0.0225 - 0.01346 * DBHT + 0.00326 * DBHT * DBHT + 0.00000
     1* BAST * BAST - 0.0001931 * DBHT * BAST
  150 IF(TOTT .LT. 0.0) DENO = 0.0
      DENO = DENST * (1.0 - DENEC * 0.5
      DEN = DENO
      T = TOTT
      GO TO 153
  152 TOTT = T
      T = TOTT + 0.05464 * DBHT * DBHT
C
C  COMPUTE HTSO FROM AGE AND SITE INDEX.
C
      IF(KAK .EQ. 2) GO TO 157
      IF(AGEO .GT. 55.0) GO TO 154
      HTSO = 1.01441 * AGEO * SITE - 0.12162 * AGEO - 1.50593
      GO TO 155
  154 HTSO = .55347 - 61.5 19 / AGEO + 1.80522 * ALOG10(SITE) + 20.5252
     1* ALOG10(SITE) / AGEO
      HTSO = 10.0 ** HTSO
  155 HTSO = HTSO + HTSM
      TOTT = TOTT * (DBHO * HTSO
      IF(D2H .GT. 6000.0) GO TO 156
      TOTT = (0.00225 * D2H - 0.00074 * BASC + 0.03711) * DENO
      GO TO 160
  156 TOTO = (0.00247 * D2H + 0.00130 * BASC - 1.40286) * DENO
      GO TO 160
  157 IF(AGEO .GT. 45.0) GO TO 158
      HTSO = 3.96111 - 0.05379 * AGEO + 1.01215 * AGEO * SITE
      GO TO 159
  158 HTSO = (3.33461 - 33.2866 / AGEO + 0.92341 * ALOG10(SITE) + 6.27811
     1* ALOG10(SITE) / AGEO
      HTSO = 10.0 ** HTSO
  159 TOTO = 0.50 * BASO * HTSO + 16.96
C
C  CONVERT TOTAL CU. FT. TO OTHER UNITS.
C
  160 IF(DBHO .LT. 5.0) GO TO 161
      KNO = 1
      BA(1) = BASO
      VOL(1) = DBHO
      CALL VOLS
      BDFO(N) = TOTO * PROD(1)
      CFMO(N) = TOTO * FCTR(1)
  161 IF(IL .EQ. IK) GO TO 165
C
C  WRITE VALUES FOR END OF PERIOD IF THINNING NOT DUE.
C
      KDENC = DENO + 0.5
      KHTSC = HTSO + 0.5
      KBASC = BASO + 0.5
      KTOTO = TOTO + 0.5
      JCFMO = CFMO(N) + 0.5
      CFMO(N) = JCFMO
      JBDFO = BDFO(N) * 0.1 + 0.5
      JBDFO = JBDFO * 10
      BDFO(N) = JBDFO
      BDFO(N) = BDFO(N) * .001
      WRITE (6,140) AGEO,KDENO,KBASO,DBHO,KHTSO,KTOTO,CFMO(N),BDFO(N)
      DBHT = DBHO
      BAST = BASO
      DENT = DENO
  163 CONTINUE
C
C  INCREASE D.B.H. BY THINNING AND COMPUTE POST-THINNING VALUES.
C
  165 REST = DLEV(KAK)
      CALL CUTS
  186 CONTINUE
  185 IROT = ROTA
      MNK = RINT
      NVOL = ((IROT - N1)/MNK) + 1
      K = NVOL + 1
C
C  INTERPOLATE BETWEEN VALUES FROM YIELD TABLE.
C
      DO 186 L=1,K
      DO 186 J=1,MNK
      N = J + N1 + (L - 1) * MNK
      ITEM = J - 1
      N = N1 + (L - 1) * MNK
      ANCUV(NN)=CFMO(N)-CFMC(N)+(ITEM/RINT)*(CFMO(N+MNK)-CFMO(N)+CFMC(N))
      ANBDF(NN) BDFO(N)-BDFC(N)+(ITEM/RINT)*(BDFO(N+MNK)-BDFO(N)+BDFC(N))
  186 CONTINUE
C
C  PRINT PAGE TYPE 11 - ANNUAL VOLUMES PER ACRE.
C
C  WRITE TABLE HEADINGS.
C
      WRITE (6,189)
  189 FORMAT (1H1,//,61X,12HPAGE TYPE 11)
      WRITE (6,190) QUAL(KAK),CYCL,THIN(KAK),DLEV(KAK)
  190 FORMAT (1HO,41X,53HGROWING STOCK OF MANAGED, REGULATED, EVEN-AGED
     1STANDS/1H ,47X,10HSITE INDEX,F5.0,1H,,F5.0,19H-YEAR CUTTING CYCLE/
     21H ,53X,14HDENSITY LEVEL-,F5.0,1X,3HAND,F5.0)
      IF(KAK .EQ. 2) GO TO 191
      WRITE (6,131)
      GO TO 192
  191 WRITE (6,133)
  192 WRITE (6,193)
  193 FORMAT (1HO,43X,44HVOLUMES PRESENT PER ACRE AT END OF EACH YEAR,/)
      WRITE (6,194)
  194 FORMAT (1HO,54X,23HMERCHANTABLE CUBIC FEET/1HO,64X,4HYEAR/1H ,14X,
     16HDECADE,9X,1HO,9X,1H1,9X,1H2,9X,1H3,9X,1H4,9X,1H5,9X,1H6,9X,1H7,9
     2X,1H8,9X,1H9,//)
      K = 0
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C
C WRITE CORD FEET PER ACRE FOR EACH YEAR.
C
      WRITE (6,196) K,(ANCUV(NN),NN=1,10)
  196 FORMAT (1H ,I2,/,F13.1,9F10.1)
      MAX = RAGE(KAK,KAN) + 1.0
      DO 197 I=1,MAX
      J = I - 1
      NN = J * 10 + 1
      WRITE (6,198) J,ANCUV(NN),ANCUV(NN+1),ANCUV(NN+2),ANCUV(NN+3),ANCUV
     1(NN+4),ANCUV(NN+5),ANCUV(NN+6),ANCUV(NN+7),ANCUV(NN+8),ANCUV(NN+9)
  197 CONTINUE
      I = MAX + 0.1
      ANCUV(IROT+1) = CFMC(IROT)
      WRITE (6,198) J,ANCUV(IROT+1)
C
C WRITE BOARD FEET PER ACRE FOR EACH YEAR.
C
      WRITE (6,147)
  147 FORMAT (1H1,///,55X,23HTHOUSANDS OF BOARD FEET,//)
      WRITE (6,196) K,(ANBDF(NN),NN=1,10)
  198 FORMAT (1H ,I2,F13.3,9F10.3)
      DO 199 I=1,MAX
      NN = I * 10 + 1
      WRITE (6,198)J,ANBDF(NN),ANBDF(NN+1),ANBDF(NN+2),ANBDF(NN+3),ANBDF
     1(NN+4),ANBDF(NN+5),ANBDF(NN+6),ANBDF(NN+7),ANBDF(NN+8),ANBDF(NN+9)
  199 CONTINUE
      I = MAX + 0.1
      ANBDF(IROT+1) = MBFC(IROT)
      WRITE (6,198) J,ANBDF(IROT+1)
C
C COMPUTE M.A.I. FOR EACH WORKING GROUP AND SITE CLASS.
C
      TEM = 0.0
      REM = 0.0
      MAX = RAGE(KAK,KAN) - DELAY(KAK)
      DO 200 I=1,MAX
      TEM = TEM + BDFC(I)
  200 REM = REM + CFMC(I)
      REM = REM * 0.01
      MNK = MNK + 1
      BDAI = ANBDF(MNK) + (SHELT(KAK)*GROWB(KAK)*0.01*FINL(KAK)) + TEM
      BDAI = BDAI / RAGE(KAK,KAN)
      CFAI = ANCUV(MNK) * 0.01 + (SHWD(KAK) * GROWC(KAK) * 0.01 * FINL(K
     1AK)) + REM
      CFAI = CFAI / RAGE(KAK,KAN)
      BDMAI(KAK) = BDMAI(KAK) + BDAI * AREA(KAK,KAN)
      CUMAI(KAK) = CUMAI(KAK) + CFAI * AREA(KAK,KAN)
C
C COMPUTE ACRES IN EACH AGE CLASS WITH IDEAL CONDITIONS.
C
      ANCUT(KAK,KAN) = AREA(KAK,KAN) / RAGE(KAK,KAN)
C
C CHANGE VALUE OF CLASS IF AGE CLASSES ARE NOT 10 YEARS.
C
      CLASS = 10.0
      TEM = ANCUT(KAK,KAN) * CLASS
      IF(DELAY(KAK) .EQ. 0.0) GO TO 204
      IF(SHWD(KAK) .GT. 0.0) GO TO 204
      PDCUT(1) = ANCUT(KAK,KAN) * DELAY(KAK)
      MNK = (RAGE(KAK,KAN) - DELAY(KAK) + 9.0) * 0.1
      IK = MNK + 1
      DO 202 I=2,MNK
  202 PDCUT(I) = TEM
      TEM = MNK - 1
      TEM = RAGE(KAK,KAN) - DELAY(KAK) - (CLASS * TEM)
      PDCUT(IK) = ANCUT(KAK,KAN) * TEM
      GO TO 206
  204 MNK = ((RAGE(KAK,KAN) + 9.0) * 0.1) + 1.0
      DO 205 I=2,MNK
  205 PDCUT(I) = TEM
C
C COMPUTE GROWING STOCK IN EACH AGE CLASS WITH IDEAL CONDITIONS.
C
  206 MAX = RAGE(KAK,KAN) - DELAY(KAK) + 1.0
      DO 210 I=1,MAX
      IF(ANBDF(I) .LT. BFMRCH) GO TO 210
      MID = I
      GO TO 211
  210 CONTINUE
  211 MES = MID - 1
      MUD = MIN + 1
      DO 212 J=MUD,MES
  212 SUBCF(KAK,KAN) = SUBCF(KAK,KAN) + ANCUV(J) * 0.01
      SUBCF(KAK,KAN) = SUBCF(KAK,KAN) * ANCUT(KAK,KAN)
      DO 213 K=MID,MAX
  213 CFBF(KAK,KAN) = CFBF(KAK,KAN) + ANCUV(K) * 0.01
      CFBF(KAK,KAN) = CFBF(KAK,KAN) * ANCUT(KAK,KAN)
      DO 215 I=1,15
      DO 214 J=2,11
      K = J + 10 * I - 10
      IF(K .GT. MAX) GO TO 217
      IF(K .LT. MID) GO TO 214
      CMS(I) = CMS(I) + ANCUV(K) * 0.01
      IF(K .LT. MID) GO TO 214
      BFS(I) = BFS(I) + ANBDF(K)
  214 CONTINUE
  215 CONTINUE
C
C ADD SHELTERWOOD OR SEED TREES, IF ANY, TO OPTIMUM GROWING STOCK.
C PROVICE FOR VOLUME GROWTH DURING REGENERATION PERIOD.
C
  217 IF(SHWD(KAK) .EQ. 0.0) GO TO 226
      K = (FINL(KAK) + 4.0) * 0.1
C
C CHANGE VALUE OF CLASS IF AGE CLASSES ARE NOT 10 YEARS.
C
      CLASS = 10.0
      REM = CLASS
      IF(FINL(KAK) .LT. CLASS) REM = FINL(KAK)
      IF(DELAY(KAK) .GT. 0.0) GO TO 220
      DO 219 NX=1,K
      TEM = NX
      IF(REM .GT. 0.0 .AND. REM .LT. CLASS) TEM = REM
      IM = NX
      MNK = (TEM - 1.0) * CLASS + 1.
      KNM = CLASS * TEM
      DO 218 KU=MNK,KNM
      TMPY = KU
  218 DMY = DMY + TMPY
      BFS(NX) = BFS(NX) + SHELT(KAK) * CLASS + SHELT(KAK) * GROWB(KAK) *
     10.01 * DMY
      CMS(NX) = CMS(NX) + SHWD(KAK) * CLASS + SHWD(KAK) * GROWC(KAK) *
     10.01 * DMY
      REM = FINL(KAK) - CLASS * TEM
      IF(REM .LE. 0.0) GO TO 226
  219 CONTINUE
      GO TO 224
  220 J = (DELAY(KAK) + 9.0) * 0.1
      L = RAGE(KAK,KAN) * 0.1
      DO 225 I=1,K
      TEM = I
      IF(REM .GT. 0.0 .AND. REM .LT. CLASS) CLASS = REM
      DMY = 0.0
      MNK = (TEM - 1.0) * CLASS + 1.0
      KNM = CLASS * TEM
      DO 221 KU = MNK,KNM
      TMPY = KU
  221 DMY = DMY + TMPY
      IF(I .GT. J) GO TO 223
      NX = L + I - J
      GO TO 224
  223 NX = I-J
  224 BFS(NX) = BFS(NX) + SHELT(KAK) * CLASS + SHELT(KAK) * GROWB(KAK) *
     10.01 * DMY
      CMS(NX) = CMS(NX) + SHWD(KAK) * CLASS + SHWD(KAK) * GROWC(KAK) *
     10.01 * DMY
      REM = FINL(KAK) - CLASS * TEM
      IF(REM .LE. 0.0) GO TO 226
  225 CONTINUE
  226 DO 227 L=1,15
      BFS(L) = BFS(L) * ANCUT(KAK,KAN)
      CMS(L) = CMS(L) * ANCUT(KAK,KAN)
  227 CONTINUE
      DO 228 I=1,15
      ALLCF(KAK,KAN) = ALLCF(KAK,KAN) + CMS(I)
  228 SUBBF(KAK,KAN) = SUBBF(KAK,KAN) + BFS(I)
      GVLBF(KAK) = GVLBF(KAK) + SUBBF(KAK,KAN)
      GVLCU(KAK) = GVLCU(KAK) + SUBCF(KAK,KAN)
C
C COMPUTE POTENTIAL ANNUAL CUTS WITH BALANCED DISTRIBUTION OF AGE
C CLASSES AND OPTIMUM GROWING STOCK FOR OBJECTIVES.
C INTERMEDIATE, REGENERATION, AND FINAL CUTS KEPT SEPARATE HERE.
C
      MNK = RAGE(KAK,KAN) - DELAY(KAK) + 1.0
      TMPY = ANBDF(MNK) - SHELT(KAK)
      IF(TMPY .LT. COMBF(KAK)) GO TO 230
      OPBD(KAK) = OPBD(KAK) + TMPY * ANCUT(KAK,KAN)
      GO TO 231
  230 TEM = ANCUV(MNK) * 0.01 - SHWD(KAK)
      IF(TEM .LT. COMCU) GO TO 231
      OPCU(KAK) = OPCU(KAK) + TEM * ANCUT(KAK,KAN)
  231 IF(SHWD(KAK) .EQ. 0.0) GO TO 233
      TEM = SHELT(KAK) * (1.0 + FINL(KAK) * GROWB(KAK) * 0.01)
      IF(TEM .LT. COMBF(KAK)) GO TO 232
      FNBD(KAK) = FNBD(KAK) + TEM * ANCUT(KAK,KAN)
      GO TO 233
  232 TEM = SHWD(KAK) * (1.0 + FINL(KAK) * GROWC(KAK) * 0.01)
      IF(TEM .LT. COMCU) GO TO 233
      FNCU(KAK) = FNCU(KAK) + TEM * ANCUT(KAK,KAN)
  233 MNK = RAGE(KAK,KAN) - CYCL
      NR = CYCL
      DO 235 I=N1,MNK,NR
      ACTEM = ACTEM + 1.0
      IF(BDFC(I) .LT. COMBF(KAK)) GO TO 234
      BFTEM = BFTEM + BDFC(I)
      GO TO 235
  234 TEM = CFMC(I) * 0.01
      IF(TEM .LT. COMCU) GO TO 235
      CFTEM = CFTEM + TEM
  235 CONTINUE
      ACINT(KAK) = ACINT(KAK) + ACTEM * ANCUT(KAK,KAN)
      BFINT(KAK) = BFINT(KAK) + BFTEM * ANCUT(KAK,KAN)
      CUINT(KAK) = CUINT(KAK) + CFTEM * ANCUT(KAK,KAN)
C
C PRINT PAGE TYPE 12 - GROWING STOCK GOALS BY WORKING GROUP AND SITE.
C
      WRITE (6,236)
  236 FORMAT (1H1,///,58X,17HPAGE TYPE 12,/)
      WRITE (6,237) QUAL(KAN),RAGE(KAK,KAN),AREA(KAK,KAN)
  237 FORMAT (1HO,41X,44HDISTRIBUTION OF AREA AND GROWING STOCK GOALS/1H
     1 ,16X,21HFOR SITE INDEX CLASS-,F5.0,11H, ROTATION-,F5.0,5H, AND,F1
     2 0.1,35H ACRES OF THIS SITE CLASS AND GROUP)
      IF(KAK .EQ. 2) GO TO 238
      WRITE (6,131)
      GO TO 239
  238 WRITE (6,133)
  239 WRITE (6,240)
  240 FORMAT (1HO,44X,8HACRES IN,13X,11HHUNDREDS OF/1H ,23X,9HAGE CLASS,
     114X,5HCLASS,16X,7HCU. FT.,17X,9HM BD. FT.,/)
      IF(SHWD(KAK) .GT. 0.0) GO TO 242
      IF(DELAY(KAK) .EQ. 0.0) GO TO 242
      WRITE (6,241) PDCUT(1)
  241 FORMAT (1HO,27X,1HO,14X,F10.1)
  242 MNK = (RAGE(KAK,KAN) + 9.0) * 0.1 + 1.0
      DO 244 I=2,KNM
      J = I - 1
      MNK = 1 + 1. * I - 10.
      IK = MNK + 1
      WRITE (6,243) MNK,IK,PDCUT(I),CMS(J),BFS(J)
```

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  243 FORMAT (1HO,24X,I3,1H-,I3,11X,F10.1,10X,F15.1,10X,F15.1)
  244 CONTINUE
      WRITE (6,245) AREA(KAK,KAN),ALLCF(KAK,KAN),SUBBF(KAK,KAN)
  245 FORMAT (1HO,//,26X,6HTOTALS,11X,F10.1,10X,F15.1,10X,F15.1)
      IF(SHWD(KAK) .GT. 0.0) GO TO 247
      IF(DELAY(KAK) .EQ. 0.0) GO TO 247
      WRITE (6,246) DELAY(KAK)
  246 FORMAT (1HO,//,17X,80HAGE CLASS ZERO REPRESENTS CLEARCUT ACRES NOT
     1 YET REFORESTED BECAUSE OF DELAY OF ,F4.0,6H YEARS/1H ,46HEXPECTED
     2 AFTER SCHEDULED REGENERATION CUTTING.)
  247 DO 248 I=1,15
      BFAGE(KAK,I) = BFAGE(KAK,I) + BFS(I)
  248 CFAGE(KAK,I) = CFAGE(KAK,I) + CMS(I)
C
C COMPUTE TOTAL YIELDS PER ACRE.
C
      NR = RAGE(KAK,KAN)
      MNK = RAGE(KAK,KAN) - CYCL
      DO 251 I=1,MNK
      IF(BOFC(I) .LT. COMBF(KAK)) GO TO 250
      VLBF(KAN) = VLBF(KAN) + BOFC(I)
  250 TEM = CFMC(I) * 0.01
      IF(TEM .LT. COMCU) GO TO 251
      VLCU(KAN) = VLCU(KAN) + TEM
  251 CONTINUE
      VLBF(KAN) = VLBF(KAN) + BOFO(NR)
      VLCU(KAN) = VLCU(KAN) + CFMO(NR) * 0.01
  252 SITE = SITE + 10.0
  253 CONTINUE
C
C REMOVE EXCESS INITIAL CONDITION CARDS.
C
  260 READ (5,45) AGEO,DENO,DBHO
      IF(AGEO .EQ. 0.0 .OR. AGEO .GT. ROTA) GO TO 261
      GO TO 260
  261 DO 262 I=KSI,KND
  262 SUMCF(KAK) = SUMCF(KAK) + ALLCF(KAK,I)
C
C COMPUTE STANDARD ACRES FOR SITE CLASSES.
C
      TEM = NSI(KAK)
      MNK = TEM * 0.5 + 0.5
      MNK = MNK + KSI - 1
      DO 271 I=KSI,KND
      IF(VLBF(MNK) .EQ. 0.0) GO TO 270
      FAC(I) = VLBF(I) / VLBF(MNK)
      STDAC(I) = AREA(KAK,I) * FAC(I)
      SSTAC = SSTAC + STDAC(I)
      IF(FAC(I) .EQ. 0.0) GO TO 270
      EQIV(I) = 1.0 / FAC(I)
  270 IF(VLCU(MNK) .EQ. 0.0) GO TO 271
      FACCF(I) = VLCU(I) / VLCU(MNK)
      STACF(I) = AREA(KAK,I) * FACCF(I)
      SACCF = SACCF + STACF(I)
      IF(FACCF(I) .EQ. 0.0) GO TO 271
      EQVCF(I) = 1.0 / FACCF(I)
  271 CONTINUE
C
C PRINT PAGE TYPE 13 - GROWING STOCK GOALS BY WORKING GROUP AND SITE.
C
      WRITE (6,299)
  299 FORMAT (1H1,///,61X,12HPAGE TYPE 13)
      WRITE (6,300)
  300 FORMAT (1HO,//,47X,38HGROWING STOCK GOALS FOR WORKING CIRCLE)
      IF(KAK .EQ. 2) GO TO 301
      WRITE (6,131)
      GO TO 302
  301 WRITE (6,133)
  302 WRITE (6,303) (FORET(I),I=1,3)
  303 FORMAT (1H ,54X,3A8,////)
      WRITE (6,304)
  304 FORMAT (1HO,45X,8HROTATION,11X,10HCU. FT. TO,13X,10HCU. FT. TO,10X
     1,15HM BD. FT. ABOVE)
      WRITE (6,305)
  305 FORMAT (1H ,10X,10HSITE CLASS,10X,5HACRES,12X,3HAGE,13X,13HBD. FT.
     1 LIMIT,10X,12HROTATION AGE,10X,13HBD. FT. LIMIT,///)
      DO 307 I=KSI,KND
      WRITE (6,306) QUAL(I),AREA(KAK,I),RAGE(KAK,I),SUBCF(KAK,I),ALLCF(K
     1AK,I),SUBBF(KAK,I)
  306 FORMAT (1HO,11X,F5.0,12X,F9.1,10X,F4.0,12X,F12.0,10X,F12.0,8X,F14.
     10)
  307 CONTINUE
      WRITE (6,308) SARSP(KAK),GVLCU(KAK),SUMCF(KAK),GVLBF(KAK)
  308 FORMAT (1HO,12X,6HTOTALS,9X,F10.1,25X,F13.0,9X,F13.0,7X,F15.0)
      WRITE (6,309)
  309 FORMAT (1HO,//,13X,101HCUBIC FEET IN HUNDREDS. TOTAL AREA INCLUDES
     1 ANY LOW SITE ACRES INCORRECTLY CLASSED AS OPERABLE TYPES.)
C
C PRINT PAGE TYPE 14 - STANDARD ACRES AND EQUIVALENT AREAS.
C
      WRITE (6,310)
  310 FORMAT (1H1,//,60X,12HPAGE TYPE 14)
      WRITE (6,311)
  311 FORMAT (1HO,/,47X,37HCONVERSION OF AREAS TO STANDARD ACRES)
      IF(KAK .EQ. 2) GO TO 312
      WRITE (6,131)
      GO TO 313
  312 WRITE (6,133)
  313 WRITE (6,303) (FORET(I),I=1,3)
      WRITE (6,314)
  314 FORMAT (1HO,9X,4HSITE,13X,11HTOTAL YIELD,13X,5HACRES,34X,7HAREA IN
     1,13X,13HEQUIVALENT OF)
      WRITE (6,315)
  315 FORMAT (1H ,9X,5HINDEX,13X,8HPER ACRE,14X,7HIN SITE,12X,9HREDUCTIO
     1N,12X,8HSTANDARD,12X,13HSTANDARD ACRE)
      WRITE (6,316)
  316 FORMAT (1H ,9X,5HCLASS,13X,9HM BD. FT.,14X,5HCLASS,14X,6HFACTOR,15
     1X,5HACRES,14X,13HIN SITE ACRES,//)
      DO 318 I=KSI,KND
      WRITE (6,317) QUAL(I),VLBF(I),AREA(KAK,I),FAC(I),STDAC(I),EQIV(I)
  317 FORMAT(1HO,8X,F5.0,12X,F9.1,12X,F10.1,11X,F9.5,11X,F10.1,13X,F9.5)
  318 CONTINUE
      WRITE (6,319) SARSP(KAK),SSTAC
  319 FORMAT (1HO,/,10X,6HTOTALS,29X,F12.1,29X,F12.1,////)
      WRITE (6,314)
      WRITE (6,315)
      WRITE (6,330)
  330 FORMAT (1H ,9X,5HCLASS,14X,7HCU. FT.,15X,5HCLASS,14X,6HFACTOR,15X,
     15HACRES,14X,13HIN SITE ACRES,//)
      DO 331 I=KSI,KND
      WRITE(6,317)QUAL(I),VLCU(I),AREA(KAK,I),FACCF(I),STACF(I),EQVCF(I)
  331 CONTINUE
      WRITE (6,332) SARSP(KAK),SACCF
  332 FORMAT (1HO,/,10X,6HTOTALS,29X,F12.1,29X,F12.1)
  400 CONTINUE
      RETURN
      END
      SUBROUTINE GUIDE
C
C TO COMPUTE DIFFERENCES BETWEEN PRESENT VOLUMES AND STOCKING GOALS AND
C TO PREPARE A GUIDE FOR FUTURE MANAGEMENT.
C
      COMMON ABFAG(3,15),ACBAR(5),ACSI(3,5,10),ACSP(3,5),ALLCF(3,10),AMC
     1AG(3,15),ANCUT(3,10),ARBK(5),AREA(3,10),BARSI(5,10),BFAGE(3,15),BF
     2TH(5,12),BFMRCH,CFAGE(3,15),CFBF(3,10),CMTH(5,12),COMBF(3),COMCU,C
     3UTAT(5,12),CUTR(5,12),CYCL,DATE(3),DLEV(3),FINL(3),FORET(3),GRBD(3,
     45,15),GRMC(3,5,15),GROWB(3),GROWC(3),GVLBF(3),GVLCU(3),MIN,NBK,NCM
     5P,NSBK(5),NSI(3),NSUB,OPEN(5,12),PCOR(3),PRET,RAGE(3,10),RINT,ROTA
     6,SARETY(5,20),SARSP(3),SBARB,SBARE,SBARG,SBF(3),SHELT(3),SHWD(3),S
     7LAND,SLVG(5,12),SMC(3),SMSP(3),STYP(20),SUBBF(3,10),SUBCF(3,10),SU
     8MCF(3),THIN(3),TMBR,TMPD,TYPNM(20),DELAY(3),ACFNL(3,5,15),ACRGN(3,
     95,15),TIME,PDCFR(5,12),PDCFN(5,12),OPCU(3),FNCU(3),CUINT(3),ACINT(
     13),FNBD(3),BFINT(3),OPBD(3),TEM,MNK,KNO,FCTR(2),PROD(2),KAK,VOM(2)
     2,ADJ(3),ALOWC(3),ALWBF(3),BDMAI(3),CUMAI(3),PAIBD(3),PAICU(3),DBHO
     3,DENO,REST,DBHT,BAST,NWGP,HELP(5,12),BA(2)
C
      DIMENSION DFBF(3,15),DFMC(3,15),SATH(3),SBFR(3),SBH(3),SBM(3,5),SB
     1SV(3),SCA(3,5),SCB(3,5),SCU(3,5),SCUR(3),SDBF(3),SDMC(3),SFR(3),SC
     2P(3,5),SSL(3,5),STBS(10),STFO(10),STHR(10),STLV(10),STNC(10),STON(
     310),SANCUT(3),SFNL(3),SOPTA(3),SOPTB(3),SOPTC(3),RGAC(3),FNAC(3),T
     4HAC(3),RGCU(3),FINC(3),THCU(3),RGBD(3),FINB(3),THBD(3),TOTAC(3),TO
     5TCU(3),TOTBD(3),SCNB(3,5),SCRB(3,5),SCNT(10),SCRT(10),SCN(3),SCR(3
     6),SHL(3,5),STHP(10),SAHP(3)
C
C INITIALIZE VARIABLES COMPLTED BY THIS ROUTINE.
C
      DO 1 I=1,3
      FNAC(I) = 0.0
      RGAC(I) = 0.0
      SAHP(I) = 0.0
      SANCUT(I) = 0.0
      SATH(I) = 0.0
      SBFR(I) = 0.0
      SBH(I) = 0.0
      SBSV(I) = 0.0
      SCN(I) = 0.0
      SCR(I) = 0.0
      SCUR(I) = 0.0
      SDBF(I) = 0.0
      SDMC(I) = 0.0
      SFNL(I) = 0.0
      SFR(I) = 0.0
      SOPTA(I) = 0.0
      SOPTB(I) = 0.0
      SOPTC(I) = 0.0
      DO 1 J=1,5
      SBM(I,J) = 0.0
      SCA(I,J) = 0.0
      SCB(I,J) = 0.0
      SCNB(I,J) = 0.0
      SCRB(I,J) = 0.0
      SCU(I,J) = 0.0
      SHL(I,J) = 0.0
      SOP(I,J) = 0.0
      SSL(I,J) = 0.0
    1 CONTINUE
      DO 2 I=1,3
      DO 2 J=1,15
      DFBF(I,J) = 0.0
    2 DFMC(I,J) = 0.0
      DO 3 I=1,10
      SCNT(I) = 0.0
      SCRT(I) = 0.0
      STBS(I) = 0.0
      STFO(I) = 0.0
      STHP(I) = 0.0
      STHR(I) = 0.0
      STLV(I) = 0.0
      STNC(I) = 0.0
    3 STON(I) = 0.0
      ANNAC = 0.0
      ANNBD = 0.0
      ANNCU = 0.0
      SIDLA = 0.0
      SIDLB = 0.0
      SIDLC = 0.0
      STHBF = 0.0
      STHCM = 0.0
      OURS = SLAND - STYP(17)
C
C COMPUTE DIFFERENCES BETWEEN ACTUAL AND DESIRED GROWING STOCKS.
C
      DO 10 I=1,NWGP
      DO 10 J=1,15
      DFBF(I,J) = ABFAG(I,J) - BFAGE(I,J)
   10 DFMC(I,J) = AMCAG(I,J) - CFAGE(I,J)
C
C COMPUTE TOTAL DIFFERENCES BETWEEN ACTUAL AND DESIRED STOCKS.
C
      DO 11 I=1,NWGP
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      DO 11 J=1,15
      SBAF(I) = SBAF(I) + DFBF(I,J)
   11 SDMC(I) = SDMC(I) + DFMC(I,J)
C
C PRINT PAGE TYPE 2 - ACTUAL AND DESIRED GROWING STOCKS AND DIFFERENCES.
C
      DO 40 KA=1,NWGP
      WRITE (6,15)
   15 FORMAT (1H1,/,60X,11HPAGE TYPE 2)
      WRITE (6,16)
   16 FORMAT (1HO,34X,54HCOMPARISON OF ACTUAL GROWING STOCK WITH GROWING
     1 STOCK GOAL)
      WRITE (6,17) (FORFT(I),I=1,3)
   17 FORMAT (1H ,54X,3A8)
      IF(KA .EQ. 2) GO TO 19
      WRITE (6,18)
   18 FORMAT (1HO,56X,18HPINE WORKING GROUP,/)
      GO TO 25
   19 WRITE (6,20)
   20 FORMAT (1HO,55X,20HSPRUCE WORKING GROUP,/)
   25 WRITE (6,26)
   26 FORMAT (1H ,34X,62HTHOUSANDS OF BOARD FEET IN TREES 10.0 INCHES D.
     1B.H. AND LARGER,/)
      WRITE (6,27)
   27 FORMAT (1HO,12X,3HAGE,11X,14HACTUAL GROWING,10X,13HGROWING STOCK,1
     15X,6HVOLUME,15X,9HSTATUS OF)
      WRITE (6,28)
   28 FORMAT (1H ,11X,5HCLASS,14X,5HSTOCK,19X,4HGOAL,18X,10HDIFFERENCE,1
     11X,13HACTUAL VOLUME,/)
      DO 34 I=1,15
      J = I * 10
      IF(DFBF(KA,I) .LT. 0.0) GO TO 30
      IF(DFBF(KA,I) .EQ. 0.0) GO TO 32
      WRITE (6,29) J,ABFAG(KA,I),BFAGE(KA,I),DFBF(KA,I)
   29 FORMAT (1H ,12X,I3,11X,F14.1,9X,F14.1,9X,F14.1,14X,7HSURPLUS)
      GO TO 34
   30 WRITE (6,31) J,ABFAG(KA,I),BFAGE(KA,I),DFBF(KA,I)
   31 FORMAT (1H ,12X,I3,11X,F14.1,9X,F14.1,9X,F14.1,14X,7HDEFICIT)
      GO TO 34
   32 WRITE (6,33) J,ABFAG(KA,I),BFAGE(KA,I),DFBF(KA,I)
   33 FORMAT (1H ,12X,I3,11X,F14.1,9X,F14.1,9X,F14.1,14X,7HCORRECT)
   34 CONTINUE
      WRITE (6,35) SBF(KA),GVLBF(KA),SDBF(KA)
   35 FORMAT (1HO,11X,5HTOTAL,10X,F14.1,9X,F14.1,9X,F14.1,/)
      WRITE (6,36)
   36 FORMAT (1HO,31X,67HHUNDREDS OF MERCH. CUBIC FEET IN TREES 6.0 INCH
     1ES D.B.H. AND LARGER,/)
      WRITE (6,27)
      WRITE (6,28)
      DO 39 I=1,15
      J = I * 10
      IF(DFMC(KA,I) .LT. 0.0) GO TO 37
      IF(DFMC(KA,I) .EQ. 0.0) GO TO 38
      WRITE (6,29) J,AMCAG(KA,I),CFAGE(KA,I),DFMC(KA,I)
      GO TO 39
   37 WRITE (6,31) J,AMCAG(KA,I),CFAGE(KA,I),DFMC(KA,I)
      GO TO 39
   38 WRITE (6,33) J,AMCAG(KA,I),CFAGE(KA,I),DFMC(KA,I)
   39 CONTINUE
      WRITE (6,35) SMC(KA),SUMCF(KA),SDMC(KA)
   40 CONTINUE
C
C SUMMARIZE VOLUMES EXPECTED DURING NEXT PERIOD BY BLOCK AND TYPE.
C
      DO 70 I=1,NBK
      DO 70 J=1,5
      SBM(1,I) = SBM(1,I) + BFTH(I,J)
      SCA(1,I) = SCA(1,I) + CUTA(I,J)
      SCB(1,I) = SCB(1,I) + CUTB(I,J)
      SCNB(1,I) = SCNB(1,I) + PDCFN(I,J)
      SCRB(1,I) = SCRB(1,I) + PDCFR(I,J)
      SCU(1,I) = SCU(1,I) + CMTH(I,J)
      SHL(1,I) = SHL(1,I) + HELP(I,J)
      SOP(1,I) = SOP(1,I) + OPEN(I,J)
      SSL(1,I) = SSL(1,I) + SLVG(I,J)
   70 CONTINUE
      DO 71 I=1,NBK
      DO 71 J=6,10
      SBM(2,I) = SBM(2,I) + BFTH(I,J)
      SCA(2,I) = SCA(2,I) + CUTA(I,J)
      SCB(2,I) = SCB(2,I) + CUTB(I,J)
      SCNB(2,I) = SCNB(2,I) + PDCFN(I,J)
      SCRB(2,I) = SCRB(2,I) + PDCFR(I,J)
      SCU(2,I) = SCU(2,I) + CMTH(I,J)
      SHL(2,I) = SHL(2,I) + HELP(I,J)
      SOP(2,I) = SOP(2,I) + OPEN(I,J)
      SSL(2,I) = SSL(2,I) + SLVG(I,J)
   71 CONTINUE
      DO 82 I=1,NBK
      DO 82 J=1,10
      SCNT(J) = SCNT(J) + PDCFN(I,J)
      SCRT(J) = SCRT(J) + PDCFR(I,J)
      STBS(J) = STBS(J) + BFTH(I,J)
      STFC(J) = STFC(J) + CUTB(I,J)
      STHP(J) = STHP(J) + HELP(I,J)
      STHR(J) = STHR(J) + CUTA(I,J)
      STLV(J) = STLV(J) + SLVG(I,J)
      STNC(J) = STNC(J) + CMTH(I,J)
      STCN(J) = STCN(J) + OPEN(I,J)
   82 CONTINUE
      DO 83 I=1,NWGP
      DO 83 J=1,NBK
      SAHP(I) = SAHP(I) + SHL(I,J)
      SATH(I) = SATH(I) + SOP(I,J)
      SBFR(I) = SBFR(I) + SBM(I,J)
      SBHI(I) = SBHI(I) + SCA(I,J)
      SBSV(I) = SBSV(I) + SSL(I,J)
      SCNI(I) = SCNI(I) + SCNB(I,J)
      SCRI(I) = SCRI(I) + SCRB(I,J)
      SCUR(I) = SCUR(I) + SCU(I,J)
      SFRI(I) = SFRI(I) + SCRB(I,J)
   83 CONTINUE
C
C PRINT PAGE TYPE 3 - POTENTIAL WORK LOAD AND YIELDS FOR NEXT PERIOD.
C
      DO 210 KA=1,NWGP
      WRITE (6,130)
  130 FORMAT (1H1,//,60X,11HPAGE TYPE 3)
      WRITE (6,131)
  131 FORMAT (1H ,46X,46HPOTENTIAL WORK LOAD AND YIELDS FOR NEXT PERIOD)
      WRITE (6,132) (FORFT(I),I=1,3)
  132 FORMAT (1H ,52X,3A8)
      WRITE (6,133)
  133 FORMAT (1HO,/,41X,47HACRES OF COMMERCIAL THINNING DURING NEXT PERI
     1OD)
      IF(KA .EQ. 2) GO TO 142
      WRITE (6,141)
  141 FORMAT (1HO,/,4X,5HBLOCK,12X,6HTYPE 1,13X,6HTYPE 2,13X,6HTYPE 3,13
     1X,6HTYPE 4,13X,6HTYPE 5,14X,5HTOTAL,/)
      MK = 1
      NK = 5
      GO TO 150
  142 WRITE (6,143)
  143 FORMAT (1HO,/,4X,5HBLOCK,12X,6HTYPE 6,13X,6HTYPE 7,13X,6HTYPE 8,13
     1X,6HTYPE 9,12X,7HTYPE 10,14X,5HTOTAL,/)
      MK = 6
      NK = 10
  150 DO 154 I=1,NBK
      WRITE (6,153) I,(OPEN(I,J),J=MK,NK),SOP(KA,I)
  153 FORMAT (1H ,4X,I2,10X,F11.1,5(8X,F11.1))
  154 CONTINUE
      WRITE (6,155) (STON(I),I=MK,NK),SATH(KA)
  155 FORMAT (1HO,3X,5HTOTAL,618X,F11.1)
      WRITE (6,156)
  156 FORMAT (1HO,//,44X,39HHUNDREDS OF CU. FT. REMOVED BY THINNING)
      IF(KA .EQ. 2) GO TO 157
      WRITE (6,141)
      GO TO 158
  157 WRITE (6,143)
  158 DO 159 I=1,NBK
      WRITE (6,153) I,(CMTH(I,J),J=MK,NK),SCU(KA,I)
  159 CONTINUE
      WRITE (6,155) (STNC(I),I=MK,NK),SCUR(KA)
      WRITE (6,164)
  164 FORMAT (1HO,//,50X,29HM BD. FT. REMOVED BY THINNING)
      IF(KA .EQ. 2) GO TO 165
      WRITE (6,141)
      GO TO 166
  165 WRITE (6,143)
  166 DO 167 I=1,NBK
      WRITE (6,153) I,(BFTH(I,J),J=MK,NK),SBM(KA,I)
  167 CONTINUE
      WRITE (6,155) (STBS(I),I=MK,NK),SBFR(KA)
      WRITE (6,130)
      WRITE (6,172)
  172 FORMAT (1HO,//,44X,39HM BD. FT. TO BE SALVAGED IN NEXT PERIOD)
      IF(KA .EQ. 2) GO TO 173
      WRITE (6,141)
      GO TO 174
  173 WRITE (6,143)
  174 DO 175 I=1,NBK
      WRITE (6,153) I,(SLVG(I,J),J=MK,NK),SSL(KA,I)
  175 CONTINUE
      WRITE (6,155) (STLV(I),I=MK,NK),SBSV(KA)
      WRITE (6,179)
  179 FORMAT (1HO,//,41X,46HM BD. FT. TO BE HARVESTED BY REGENERATION CU
     1TS)
      IF(KA .EQ. 2) GO TO 180
      WRITE (6,141)
      GO TO 181
  180 WRITE (6,143)
  181 DO 182 I=1,NBK
      WRITE (6,153) I,(CUTA(I,J),J=MK,NK),SCA(KA,I)
  182 CONTINUE
      WRITE (6,155) (STHR(I),I=MK,NK),SBHI(KA)
      WRITE (6,185)
  185 FORMAT (1HO,//,43X,42HHUNDREDS OF CU. FT. FROM REGENERATION CUTS)
      IF(KA .EQ. 2) GO TO 186
      WRITE (6,141)
      GO TO 187
  186 WRITE (6,143)
  187 DO 188 I=1,NBK
      WRITE (6,153) I,(PDCFR(I,J),J=MK,NK),SCRB(KA,I)
  188 CONTINUE
      WRITE (6,155) (SCRT(I),I=MK,NK),SCR(KA)
      WRITE (6,130)
      WRITE (6,193)
  193 FORMAT (1HO,//,37X,54HM BD. FT. TO BE HARVESTED BY FINAL REMOVAL O
     1F OVERWOOD)
      IF(KA .EQ. 2) GO TO 194
      WRITE (6,141)
      GO TO 195
  194 WRITE (6,143)
  195 DO 196 I=1,NBK
      WRITE (6,153) I,(CUTB(I,J),J=MK,NK),SCB(KA,I)
  196 CONTINUE
      WRITE (6,155) (STFC(I),I=MK,NK),SFR(KA)
  201 FORMAT (1HO,//,46X,35HHUNDREDS OF CU. FT. FROM FINAL CUTS)
      IF(KA .EQ. 2) GO TO 202
      WRITE (6,141)
      GO TO 203
  202 WRITE (6,143)
  203 DO 204 I=1,NBK
      WRITE (6,153) I,(PDCFN(I,J),J=MK,NK),SCNB(KA,I)
  204 CONTINUE
      WRITE (6,155) (SCNT(I),I=MK,NK),SCN(KA)
      WRITE (6,205)
  205 FORMAT (1HO,//,39X,50HACRES OF NONCOMMERCIAL THINNING DURING NEXT
     1PERIOD)
```

```
      IF(KA .EQ. 2) GO TO 206
      WRITE (6,141)
      GO TO 207
  206 WRITE (6,143)
  207 DO 208 I=1,NBK
      WRITE (6,153) I,(HELP(I,J),J=MK,NK),SHL(KA,I)
  208 CONTINUE
      WRITE (6,155) (SAHP(I),I=MK,NK),SAHP(KA)
  210 CONTINUE
C
C SUM THE ANNUAL CUTS BASED ON OPTIMUM AREA REGULATION BY WORKING AGE
C AND WORKING CIRCLE.
C
      DO 230 I=1,NWGP
      DO 230 J=1,10
  230 SANCUT(I) = SANCUT(I) + ANCUT(I,J)
      DO 235 I=1,NWGP
      SFNL(I) = SANCUT(I)
      IF(SHWD(I) .EQ. 0.0) SFNL(I) = 0.0
  235 CONTINUE
      DO 240 I=1,NWGP
      SOPTA(I) = SANCUT(I) + SFNL(I) + ACINT(I)
      SOPTB(I) = OPBD(I) + FNBD(I) + BFINT(I)
      SOPTC(I) = OPCU(I) + FNCU(I) + CUINT(I)
      SIELA = SIELA + SOPTA(I)
      SIDLB = SIDLB + SOPTB(I)
  240 SIDLC = SIDLC + SOPTC(I)
C
C COMPUTE POSSIBLE ANNUAL CUTS DURING NEXT PERIOD - BASIS WORK INDEX.
C
      DO 250 I=1,NWGP
      DO 250 J=1,NBK
      DO 250 K=1,15
      RGAC(I) = RGAC(I) + ACRGN(I,J,K)
  250 FNAC(I) = FNAC(I) + ACFNL(I,J,K)
      TFM = 1.0 / TIME
      DO 260 I=1,NWGP
      FINB(I) = SFR(I) * TFM
      FINC(I) = SCN(I) * TFM
      FNAC(I) = FNAC(I) * TFM
      RGAC(I) = RGAC(I) * TFM
      RGBD(I) = SBH(I) * TFM
      RGCU(I) = SCR(I) * TFM
      THAC(I) = (SATH(I) + SAHP(I)) * TFM
      THBD(I) = SBFR(I) * TFM
      THCU(I) = SCUR(I) * TFM
  260 CONTINUE
      DO 261 I=1,NWGP
      TOTAC(I) = RGAC(I) + FNAC(I) + THAC(I)
      TOTCU(I) = RGCU(I) + FINC(I) + THCU(I)
      TOTBD(I) = RGBD(I) + FINB(I) + THBD(I)
      ANNAC = ANNAC + TOTAC(I)
      ANNCU = ANNCU + TOTCU(I)
  261 ANNBD = ANNBD + TOTBD(I)
C
C PRINT PAGE TYPE 1 - SUMMARY OF RESULTS AND GUIDE TO MANAGEMENT.
C
      WRITE (6,299)
  299 FORMAT (1H1,//,59X,11HPAGE TYPE 1)
      WRITE (6,300) (FORET(I),I=1,3)
  300 FORMAT (1HC,//,39X,28HGUIDE FOR MANAGEMENT OF THE ,3A4,/)
      WRITE (6,302) (DATE(I),I=1,3)
  302 FORMAT (1HO,5X,25HBASED ON DATA CURRENT TO ,3A4)
      WRITE (6,304) SLAND,OURS,STYP(17),TMBR,SBARE,STYP(16),STYP(13)
  304 FORMAT (1HO,31HTHE WORKING CIRCLE CONSISTS OF ,F10.1,18H ACRES. OF
     1 THESE, ,F10.1,27H ACRES ARE OWNED BY US AND ,F10.1,19H ACRES ARE
     2INTERIOR/1H ,45HTRACTS OF OTHER OWNERSHIP. OUR AREA INCLUDES ,F10.
     31,17H TIMBERED ACRES, ,F10.1,18H PLANTABLE ACRES, ,F10.1,17H ACRES
     4 MANAGED AS/1H ,11HRANGE, AND ,F10.1,106H ACRES OF HIGH RECREATION
     5 USE WHERE TIMBER YIELDS ARE INCIDENTAL AND NOT REGULATED. SEE PAG
     6E TYPE 5, 6, 8,/1H ,30HAND 9 FOR AREA CLASSIFICATION.)
      WRITE (6,306)
  306 FORMAT (1HC,70HTHE TIMBER RESOURCE OF THIS WORKING CIRCLE WILL BE
     1MANAGED AS FOLLOWS-)
      WRITE (6,308) FINL(1)
  308 FORMAT (1H ,11X,44HPINE WORKING GROUP- TWO-CUT SHELTERWOOD WITH,F5
     1.1,38H YEARS BETWEEN REMOVAL AND FINAL CUTS.)
      WRITE (6,310)
  310 FORMAT (1H ,11X,73HSPRUCE WORKING GROUP- CLEARCUT BY SMALL AREAS W
     1ITH SEEDING FROM THE SIDE.)
      WRITE (6,320)
  320 FORMAT (1HC,58HREGULATION OF THE CUT WILL BE BY AREA WITH A VOLUME
     1 CHECK.)
      WRITE (6,322)
  322 FORMAT (1HO,125HWITH THE DECISIONS AND AREAS ON PAGES TYPE 4 AND 1
     1 3 AND WITH BALANCED DISTRIBUTION OF AGE CLASSES, ALLOWABLE ANNUAL
     2CUT WOULD/1H ,14HBE AS FOLLOWS-)
      WRITE (6,324)
  324 FORMAT (1HO,64X,11HHUNDREDS OF/1H ,42X,5HACRES,19X,7HCU. FT.,17X,9
     1HM BD. FT.)
      WRITE (6,326)
  326 FORMAT (1HO,11X,17HREGENERATION CUTS)
      WRITE (6,328) SANCUT(1),OPCU(1),OPBD(1)
  328 FORMAT (1HO,15X,18HPINE WORKING GROUP,5X,F11.1,14X,F11.1,14X,F11.1
     1)
      WRITE (6,330) SANCUT(2),OPCU(2),OPBD(2)
  330 FORMAT (1HO,15X,20HSPRUCE WORKING GROUP,3X,F11.1,14X,F11.1,14X,F11
     1.1)
      WRITE (6,340)
  340 FORMAT (1HC,11X,18HFINAL REMOVAL CUTS)
      WRITE (6,328) SFNL(1),FNCU(1),FNBD(1)
      WRITE (6,330) SFNL(2),FNCU(2),FNBD(2)
      WRITE (6,342)
  342 FORMAT (1HC,11X,17HINTERMEDIATE CUTS)
      WRITE (6,328) ACINT(1),CUINT(1),BFINT(1)
      WRITE (6,330) ACINT(2),CUINT(2),BFINT(2)
      WRITE (6,344)
  344 FORMAT (1H ,11X,19HTOTAL FOR ONE YEAR)
      WRITE (6,328) TOTAC(1),TOTCU(1),TOTBD(1)
      WRITE (6,330) TOTAC(2),TOTCU(2),TOTBD(2)
      WRITE (6,346)
  346 FORMAT (1H ,11X,19HTOTAL ALL GROWERS,11X,F11.1,14X,F11.1,14X,F11.1)
      WRITE (6,348)
  348 FORMAT (1H ,7X,14,126HHOWEVER COMMERCIAL VOLUMES INCLUDED IN THE TABLE
     1 ABOVE AND IN THE NEXT TABLE. CUTS ARE ASSIGNED TO BOARD-FOOT TOTA
     2LS IF POSSIBLE./1H ,112HTHEY APPEAR IN CUBIC-FOOT TOTALS ONLY WHEN
     3 MERCHANTABLE SAWLOG CUTS ARE NOT POSSIBLE. AREAS INCLUDE NONCOMMERC
     4IAL.)
      WRITE (6,350)
  350 FORMAT (1H1,//,56X,18HPAGE TYPE 1, CONT.)
      WRITE (6,352)
  352 FORMAT (1H ,126HEXAMINATION OF THE WORKING CIRCLE INDICATES THAT A
     1CTUAL ANNUAL CUT DURING THE NEXT PERIOD COULD BE AS SHOWN ON PAGES
     2 TYPE 3 IF/1H ,125HALL POSSIBLE CULTURAL OPERATIONS, AS INDICATED
     3 ON PAGE TYPE 5, WERE PERFORMED. IN SUMMARY, THERE IS A POTENTIAL AN
     4NUAL CUT OF-)
      WRITE (6,324)
      WRITE (6,326)
      WRITE (6,328) RGAC(1),RGCU(1),RGBD(1)
      WRITE (6,330) RGAC(2),RGCU(2),RGBD(2)
      WRITE (6,340)
      WRITE (6,328) FNAC(1),FINC(1),FINB(1)
      WRITE (6,330) FNAC(2),FINC(2),FINB(2)
      WRITE (6,342)
      WRITE (6,328) THAC(1),THCU(1),THBD(1)
      WRITE (6,330) THAC(2),THCU(2),THBD(2)
      WRITE (6,344)
      WRITE (6,328) TOTAC(1),TOTCU(1),TOTBD(1)
      WRITE (6,330) TOTAC(2),TOTCU(2),TOTBD(2)
      WRITE (6,346) ANNAC,ANNCU,ANNBD
      WRITE (6,360)
  360 FORMAT (1HO,//,1X,85HFORMULA COMPUTATION OF ALLOWABLE ANNUAL CUT.
     1CUBIC-FOOT VOLUMES INCLUDE SAWLOG TREES-)

C COMPUTE ANNUAL CUT BY HEYER FORMULA USING M.A.I. FROM YIELD TABLES.
C
      DO 380 I=1,NWGP
      IF(ADJ(I) .EQ. 0.0) GO TO 379
      ALWBF(I) = BOMAI(I) + (SDBF(I) / ADJ(I))
      ALOWC(I) = CUMAI(I) + (SDMC(I) / ADJ(I))
      GO TO 380
  379 ALWBF(I) = BOMAI(I) + SDBF(I)
      ALOWC(I) = CUMAI(I) + SDMC(I)
  380 CONTINUE
      WRITE (6,390)
  390 FORMAT (1HO,11X,79HHEYER FORMULA WITH M.A.I. FROM OPTIMUM YIELD TA
     1BLES AND COMPUTED GROWING STOCKS)
      WRITE (6,364)
  364 FORMAT (1HO,42X,10HADJUSTMENT,12X,11HHUNDREDS OF/1H ,44X,6HPERIOD,
     116X,7HCU. FT.,17X,9HM BD. FT.)
      WRITE (6,328) ADJ(1),ALOWC(1),ALWBF(1)
      WRITE (6,330) ADJ(2),ALOWC(2),ALWBF(2)
      WRITE (6,350)
      WRITE (6,392)
  392 FORMAT (1HO,11X,65HMEAN ANNUAL INCREMENTS USED TO OBTAIN THE RESUL
     1TS TABULATED ABOVE)
      WRITE (6,364)
      WRITE (6,328) ADJ(1),CUMAI(1),BOMAI(1)
      WRITE (6,330) ADJ(2),CUMAI(2),BOMAI(2)
      WRITE (6,395)
  395 FORMAT (1HO,120HFORMULA COMPUTATIONS ARE BASED ON VOLUME AND AREA
     1COMPUTATIONS SUMMARIZED ON OTHER PAGES. VOLUME GOALS ARE ON PAGES
     2TYPE/1H ,120H4, 10, 11, 12, AND 13. ACTUAL AREAS AND VOLUMES ARE O
     3N PAGES TYPE 6, 7, 8, AND 9. CUBIC VOLUMES INCLUDE ALL TREES LARGE
     4R/1H ,68HAND OLDER THAN MINIMUM LIMITS FOR INCLUSION IN GROWING ST
     5OCK VOLUME.)
      WRITE (6,400)
  400 FORMAT (1HO,124HSTANDS SELECTED FOR HARVEST AND REGENERATION WILL
     1INCLUDE THOSE CLASSED AS WORK INDEX 4, 5, OR 6. IT IS EXPECTED THA
     2T NEARLY/1H ,126HEQUAL AREAS WILL BE CUT ANNUALLY IN STANDS OF EAC
     3H SITE CLASS. IF THIS IS NOT DESIRABLE, FACTORS THAT INDICATE RELA
     4TIVE VOLUME/1H ,59HPRODUCTION (PAGE TYPE 14) MAY BE USED FOR AREA
     5ADJUSTMENTS.)
      WRITE (6,405)
  405 FORMAT (1HO,100HIF WORK IS DONE DURING NEXT PERIOD AS SPECIFIED BY
     1 WORK INDEXES, PERIODIC ANNUAL INCREMENTS WILL BE-)
      WRITE (6,406)
  406 FORMAT (1HO,44X,11HHUNDREDS OF/1H ,46X,7HCU. FT.,17X,9HM BD. FT.)
      WRITE (6,407) PAICU(1),PAIBD(1)
  407 FORMAT (1HO,15X,18HPINE WORKING GROUP,13X,F8.1,16X,F8.1)
      WRITE (6,408) PAICU(2),PAIBD(2)
  408 FORMAT (1HO,15X,20HSPRUCE WORKING GROUP,11X,F8.1,16X,F8.1)
      WRITE (6,350)
      WRITE (6,415)
  415 FORMAT (1HO,85HCORRESPONDING PERIODIC INCREMENTS WITH SAME ASSUMPT
     1IONS CONCERNING WORK ACCOMPLISHED-)
      WRITE (6,416)
  416 FORMAT (1HC,40X,18HPINE WORKING GROUP,36X,20HSPRUCE WORKING GROUP)
      WRITE (6,417)
  417 FORMAT (1H ,15X,3HAGE,14X,11HHUNDREDS OF,44X,11HHUNDREDS OF)
      WRITE (6,418)
  418 FORMAT (1H ,4X,5HBLOCK,5X,5HCLASS,15X,7HCU. FT.,15X,9HM BD. FT.,24
     1X,7HCU. FT.,15X,9HM BD. FT.,/)
      DO 420 I=1,NBK
      DO 420 J=1,15
      MA = ((J-1) * 10) + 1
      NA = J * 10
      WRITE (6,419) I,MA,NA,GRMC(1,I,J),GRBD(1,I,J),GRMC(2,I,J),GRBD(2,I
     1,J)
  419 FORMAT (1H ,5X,I2,6X,I3,1H-,I3,13X,F10.1,12X,F10.1,23X,F10.1,12X,F
     110.1)
  420 CONTINUE
      RETURN
      END
```

APPENDIX 2

An Application of TEVAP

An example of what TEVAP can do is provided by the hypothetical situation described below and by reproductions of the computer records produced. The test forest, the mythical Bogus National Forest, is managed as one working circle. The working circle is subdivided into three blocks on the basis of typography, transportation system, and distribution of wood-using plants. Total areas of each block, interior tracts of other ownership, high use recreation areas, and so forth, are known. The forest has not yet been subdivided into compartments; the AREA2 option of TEVAP is applicable.

Numerous decisions have been made concerning management objectives and how they may be attained. Past records of the forest and silvicultural characteristics of each species were considered during the planning process. Decisionmaking was assisted by computer simulation of forest activities (Myers 1968). The effects of changes in rotation length and other variables subject to control were examined. It was decided that the following controls would apply to timber management on the working circle:

Working groups.

a. Pine working group—Pine under two-cut shelterwood.
b. Spruce working group—Spruce clearcut in small patches with natural regeneration.
c. A third group is still in the planning stage—selectively-cut pine in areas of highest scenic value. Algorithms applicable to many-aged stands will be added to GOT and GOAL, when needed.

Rotations.

a. Pine group—110 years for site 40, 130 years for remainder.
b. Spruce group—90 years for site 50, 110 years for remainder.

Thinning.

a. Pine group—Initial thinning at age 30 to level 100. Subsequent thinnings at 20-year intervals to level 100.
b. Spruce group—Initial thinning at age 30 to level 100. Subsequent thinnings at 20-year intervals to level 90.

Minimum site class to be managed for wood products.

a. Pine group—site index 40.
b. Spruce group—site index 50.

Many decisions provided as inputs to the program are recorded on page type 4 of the output reproduced below. Other input data are recorded on pages of types 1, 10, and 13.

An inventory of the timber resource and analysis of the data were completed 5 years ago. At that time, summary cards with the items specified for data card type 16 were punched. The inventory file has increased annually through addition of records that describe thinning jobs and other changes in stands of known area. The inventory file now consists of 251 records, 104 of which are job and similar reports and 147 sample "unknown" parts of the working circle. All inventory records are updated to a common time base annually (Appendix 5).

Land books and other records provide the total number of acres in each block and the area occupied by nonforest vegetative and use types 13 to 17, inclusive. These acreages are recorded on pages type 5 and 6.

The output that follows requires use of data cards of all types except for types 8 to 13, inclusive. Pages appear in the order in which they might appear in a management guide, not in the order produced. For brevity, only two sheets each of pages type 10, 11, and 12 are reproduced. Complete output would include six sheets of each of these types, one for each site index class of each working group. Examples of pages produced with card types 8 to 13 appear in Appendix 3.

A management guide can be produced on microfilm annually for distribution to appropriate land managers and staff. The example below required 69.5 seconds of central processor time for compilation and execution. The time required for computation by conventional methods might be as many days!

GUIDE FOR MANAGEMENT OF THE [illegible] NATIONAL FOREST

BASED ON DATA CURRENT TO JANUARY 4, 1971

THE WORKING CIRCLE CONSISTS OF 252446.4 ACRES. OF THESE, 244641.0 ACRES ARE OWNED BY US AND 47799.4 ACRES ARE INTERIOR TRACTS OF OTHER OWNERSHIP. THE AREA INCLUDES 204947.8 TIMBERED ACRES, 25661.5 PLANTABLE ACRES, 8198.8 ACRES MANAGED AS RANGE, AND 3911.1 ACRES OF HIGH RECREATION USE WHERE TIMBER YIELDS ARE INCIDENTAL AND NOT REGULATED. SEE PAGE TYPE 5, 6, 8, AND 9 FOR AREA CLASSIFICATION.

THE TIMBER RESOURCE OF THIS WORKING CIRCLE WILL BE MANAGED AS FOLLOWS-
PINE WORKING GROUP- TWO-CUT SHELTERWOOD WITH 20.0 YEARS BETWEEN REMOVAL AND FINAL CUTS.
SPRUCE WORKING GROUP- CLEARCUT BY SMALL AREAS WITH SEEDING FROM THE SIDE.

REGULATION OF THE CUT WILL BE BY AREA WITH A VOLUME CHECK.

WITH THE DECISIONS AND AREAS ON PAGES TYPE 4 AND 13 AND WITH BALANCED DISTRIBUTION OF AGE CLASSES, ALLOWABLE ANNUAL CUT WOULD BE AS FOLLOWS-

	ACRES	HUNDREDS OF CU. FT.	M BD. FT.
REGENERATION CUTS			
PINE WORKING GROUP	1666.3	0.0	17128.4
SPRUCE WORKING GROUP	167.8	0.0	2027.6
FINAL REMOVAL CUTS			
PINE WORKING GROUP	1666.3	0.0	10664.1
SPRUCE WORKING GROUP	0.0	0.0	0.0
INTERMEDIATE CUTS			
PINE WORKING GROUP	8054.4	7071.9	7032.9
SPRUCE WORKING GROUP	644.3	1244.8	326.3
TOTAL FOR ONE YEAR			
PINE WORKING GROUP	11386.9	7071.9	34825.3
SPRUCE WORKING GROUP	812.1	1248.8	2353.9
TOTAL ALL GROUPS	12199.0	8320.7	37179.2

ONLY COMMERCIAL VOLUMES INCLUDED IN THE TABLE ABOVE AND IN THE NEXT TABLE. CUTS ARE ASSIGNED TO BOARD-FOOT TOTALS IF POSSIBLE. THEY APPEAR IN CUBIC-FOOT TOTALS ONLY WHEN COMMERCIAL SAWLOG CUTS ARE NOT POSSIBLE. AREAS INCLUDE NONCOMMERCIAL.

EXAMINATION OF THE WORKING CIRCLE INDICATES THAT ACTUAL ANNUAL CUT DURING THE NEXT PERIOD COULD BE AS SHOWN ON PAGES TYPE 3 IF ALL POSSIBLE CULTURAL OPERATIONS, AS INDICATED BY WORK CODES, WERE PERFORMED. IN SUMMARY, THERE IS A POTENTIAL ANNUAL CUT OF-

	ACRES	HUNDREDS OF CU. FT.	M BD. FT.
REGENERATION CUTS			
PINE WORKING GROUP	3588.3	9681.4	29755.7
SPRUCE WORKING GROUP	239.0	0.0	3807.6
FINAL REMOVAL CUTS			
PINE WORKING GROUP	2151.9	0.0	6900.4
SPRUCE WORKING GROUP	0.0	0.0	0.0
INTERMEDIATE CUTS			
PINE WORKING GROUP	8624.1	19270.5	3298.7
SPRUCE WORKING GROUP	773.0	5480.1	1733.8
TOTAL FOR ONE YEAR			
PINE WORKING GROUP	14364.4	28951.9	39954.8
SPRUCE WORKING GROUP	1012.0	5480.1	5541.4
TOTAL ALL GROUPS	15376.3	34431.9	45496.2

FORMULA COMPUTATION OF ALLOWABLE ANNUAL CUT. CUBIC-FOOT VOLUMES INCLUDE SAWLOG TREES-

HEYER FORMULA WITH M.A.I. FROM OPTIMUM YIELD TABLES AND COMPUTED GROWING STOCKS

	ADJUSTMENT PERIOD	HUNDREDS OF CU. FT.	M BD. FT.
PINE WORKING GROUP	30.0	74829.7	25314.5
SPRUCE WORKING GROUP	30.0	18929.9	4838.2

PAGE TYPE 1, CONT.

MEAN ANNUAL INCREMENTS USED TO OBTAIN THE RESULTS TABULATED ABOVE

	ADJUSTMENT PERIOD	HUNDREDS OF CU. FT.	M BD. FT.
PINE WORKING GROUP	30.0	84922.0	35617.8
SPRUCE WORKING GROUP	30.0	7490.2	2401.2

FORMULA COMPUTATIONS ARE BASED ON VOLUME AND AREA COMPUTATIONS SUMMARIZED ON OTHER PAGES. VOLUME GOALS ARE ON PAGES TYPE 4, 10, 11, 12, AND 13. ACTUAL AREAS AND VOLUMES ARE ON PAGES TYPE 6, 7, 8, AND 9. CUBIC VOLUMES INCLUDE ALL TREES LARGER AND OLDER THAN MINIMUM LIMITS FOR INCLUSION IN GROWING STOCK VOLUME.

STANDS SELECTED FOR HARVEST AND REGENERATION WILL INCLUDE THOSE CLASSED AS WORK INDEX 4, 5, OR 6. IT IS EXPECTED THAT NEARLY EQUAL AREAS WILL BE CUT ANNUALLY IN STANDS OF EACH SITE CLASS. IF THIS IS NOT DESIRABLE, FACTORS THAT INDICATE RELATIVE VOLUME PRODUCTION (PAGE TYPE 14) MAY BE USED FOR AREA ADJUSTMENTS.

IF WORK IS DONE DURING NEXT PERIOD AS SPECIFIED BY WORK INDEXES, PERIODIC ANNUAL INCREMENTS WILL BE-

	HUNDREDS OF CU. FT.	M BD. FT.
PINE WORKING GROUP	118077.2	47095.1
SPRUCE WORKING GROUP	18426.1	6663.4

PAGE TYPE 1, CONT.

CORRESPONDING PERIODIC INCREMENTS WITH SAME ASSUMPTIONS CONCERNING WORK ACCOMPLISHED-

		PINE WORKING GROUP		SPRUCE WORKING GROUP	
BLOCK	AGE CLASS	HUNDREDS OF CU. FT.	M BD. FT.	HUNDREDS OF CU. FT.	M BD. FT.
1	1- 10	0.0	0.0	0.0	0.0
1	11- 20	0.0	0.0	0.0	0.0
1	21- 30	8.4	0.0	0.0	0.0
1	31- 40	4979.4	0.0	0.0	0.0
1	41- 50	47312.8	435.7	550.9	40.9
1	51- 60	14230.2	0.0	0.0	0.0
1	61- 70	26498.3	1845.9	0.0	0.0
1	71- 80	35148.8	13829.5	0.0	0.0
1	81- 90	19751.9	274.5	0.0	0.0
1	91-100	111.4	69.8	0.0	0.0
1	101-110	61500.1	24610.5	19084.0	10018.7
1	111-120	21151.1	13120.2	101.0	64.7
1	121-130	107637.7	46844.0	51.9	33.4
1	131-140	11788.1	7138.9	4501.6	2675.1
1	141-150	25802.9	15689.5	0.0	0.0
2	1- 10	0.0	0.0	0.0	0.0
2	11- 20	164851.4	132458.2	0.0	0.0
2	21- 30	409.8	336.2	0.0	0.0
2	31- 40	116.2	1.3	0.0	0.0
2	41- 50	32520.1	2531.7	8799.9	0.0
2	51- 60	27999.0	5699.3	35446.5	4874.4
2	61- 70	40249.7	5914.4	182.0	21.7
2	71- 80	36220.3	9742.8	50204.1	3199.1
2	81- 90	30369.5	12720.7	0.0	0.0
2	91-100	58031.8	30563.8	11346.7	7229.1
2	101-110	54957.2	13043.4	23679.5	19167.7
2	111-120	36580.6	12010.4	446.7	306.8
2	121-130	29613.4	15067.4	0.0	0.0
2	131-140	14266.1	8082.1	0.0	0.0
2	141-150	21200.5	9430.4	0.0	0.0
3	1- 10	0.0	0.0	0.0	0.0
3	11- 20	0.0	0.0	0.0	0.0
3	21- 30	43529.0	22954.1	0.0	0.0
3	31- 40	8415.4	0.0	0.0	0.0
3	41- 50	20688.0	798.1	0.0	0.0
3	51- 60	2323.3	16.3	0.0	0.0
3	61- 70	11277.3	908.3	0.0	0.0
3	71- 80	12935.7	1954.3	0.0	0.0
3	81- 90	13257.4	5756.2	0.0	0.0
3	91-100	7350.7	3936.0	0.0	0.0
3	101-110	15109.3	8981.4	15385.5	9102.3
3	111-120	35976.5	15170.2	14480.4	9900.4
3	121-130	60397.3	18400.1	0.0	0.0
3	131-140	9449.1	5984.0	0.0	0.0
3	141-150	16756.8	4631.8	0.0	0.0

PAGE TYPE 2

COMPARISON OF ACTUAL GROWING STOCK WITH GROWING STOCK GOAL
BOGUS NATIONAL FOREST

PINE WORKING GROUP

THOUSANDS OF BOARD FEET IN TREES 10.0 INCHES D.B.H. AND LARGER

AGE CLASS	ACTUAL GROWING STOCK	GROWING STOCK GOAL	VOLUME DIFFERENCE	STATUS OF ACTUAL VOLUME
10	0.0	97643.0	-97643.0	DEFICIT
20	0.0	0.0	0.0	CORRECT
30	0.0	0.0	0.0	CORRECT
40	0.0	0.0	0.0	CORRECT
50	0.0	0.0	0.0	CORRECT
60	0.0	15731.0	-15731.0	DEFICIT
70	219.1	52258.4	-52039.3	DEFICIT
80	10330.1	99933.7	-89603.6	DEFICIT
90	16599.9	149913.2	-133313.3	DEFICIT
100	38095.3	167977.0	-129881.8	DEFICIT
110	76097.3	203417.8	-127320.5	DEFICIT
120	123900.4	199403.6	-75503.1	DEFICIT
130	215117.2	64744.1	150373.1	SURPLUS
140	103359.8	0.0	103359.8	SURPLUS
150	158204.7	0.0	158204.7	SURPLUS
TOTAL	741923.7	1051021.8	-309098.0	

HUNDREDS OF MERCH. CUBIC FEET IN TREES 6.0 INCHES D.B.H. AND LARGER

AGE CLASS	ACTUAL GROWING STOCK	GROWING STOCK GOAL	VOLUME DIFFERENCE	STATUS OF ACTUAL VOLUME
10	0.0	184955.2	-184955.2	DEFICIT
20	0.0	0.0	0.0	CORRECT
30	0.0	2448.0	-2448.0	DEFICIT
40	209.1	63022.2	-62813.1	DEFICIT
50	79628.0	146603.2	-66975.2	DEFICIT
60	49538.8	220570.1	-171031.4	DEFICIT
70	107007.9	306266.5	-199258.6	DEFICIT
80	155484.9	338672.7	-183187.8	DEFICIT
90	161272.0	417484.8	-256212.8	DEFICIT
100	170358.4	414200.1	-243841.7	DEFICIT
110	378741.9	457763.3	-79021.4	DEFICIT
120	343991.6	415929.2	-71937.6	DEFICIT
130	640935.4	126431.5	514503.9	SURPLUS
140	240455.7	0.0	240455.7	SURPLUS
150	463953.5	0.0	463953.5	SURPLUS
TOTAL	2791577.2	3094346.9	-302769.7	

PAGE TYPE 2

COMPARISON OF ACTUAL GROWING STOCK WITH GROWING STOCK GOAL
BOGUS NATIONAL FOREST

SPRUCE WORKING GROUP

THOUSANDS OF BOARD FEET IN TREES 10.0 INCHES D.B.H. AND LARGER

AGE CLASS	ACTUAL GROWING STOCK	GROWING STOCK GOAL	VOLUME DIFFERENCE	STATUS OF ACTUAL VOLUME
10	0.0	0.0	0.0	CORRECT
20	0.0	0.0	0.0	CORRECT
30	0.0	0.0	0.0	CORRECT
40	0.0	0.0	0.0	CORRECT
50	23.3	0.0	23.3	SURPLUS
60	0.0	683.4	-683.4	DEFICIT
70	0.0	4560.7	-4560.7	DEFICIT
80	0.0	10612.2	-10612.2	DEFICIT
90	0.0	15319.3	-15319.3	DEFICIT
100	21167.2	17259.5	3907.7	SURPLUS
110	62660.7	0.0	62660.7	SURPLUS
120	19411.7	0.0	19411.7	SURPLUS
130	177.3	0.0	177.3	SURPLUS
140	18104.6	0.0	18104.6	SURPLUS
150	0.0	0.0	0.0	CORRECT
TOTAL	121544.8	48435.1	73109.7	

HUNDREDS OF MERCH. CUBIC FEET IN TREES 6.0 INCHES D.B.H. AND LARGER

AGE CLASS	ACTUAL GROWING STOCK	GROWING STOCK GOAL	VOLUME DIFFERENCE	STATUS OF ACTUAL VOLUME
10	0.0	0.0	0.0	CORRECT
20	0.0	0.0	0.0	CORRECT
30	0.0	0.0	0.0	CORRECT
40	0.0	3736.5	-3736.5	DEFICIT
50	523.1	13979.6	-13456.4	DEFICIT
60	35647.9	25178.6	10469.4	SURPLUS
70	287.6	36979.8	-36692.3	DEFICIT
80	47317.7	40071.9	7245.8	SURPLUS
90	0.0	43825.7	-43825.7	DEFICIT
100	67018.1	40992.8	26025.2	SURPLUS
110	277328.2	0.0	277328.2	SURPLUS
120	72201.0	0.0	72201.0	SURPLUS
130	461.8	0.0	461.8	SURPLUS
140	47170.2	0.0	47170.2	SURPLUS
150	0.0	0.0	0.0	CORRECT
TOTAL	547955.6	204764.9	343190.7	

PAGE TYPE 3

POTENTIAL WORK LOAD AND YIELDS FOR NEXT PERIOD
BOGUS NATIONAL FOREST

ACRES OF COMMERCIAL THINNING DURING NEXT PERIOD

BLOCK	TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5	TOTAL
1	0.0	0.0	6191.2	9517.9	0.0	15709.2
2	0.0	1685.9	8069.5	3149.6	0.0	12904.9
3	0.0	0.0	2808.7	2808.7	0.0	5617.4
TOTAL	0.0	1685.9	17069.4	15476.2	0.0	34231.5

HUNDREDS OF CU. FT. REMOVED BY THINNING

BLOCK	TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5	TOTAL
1	0.0	0.0	49443.3	43527.3	0.0	92970.6
2	0.0	13626.8	51634.7	14201.9	0.0	79463.5
3	0.0	0.0	20270.8	0.0	0.0	20270.8
TOTAL	0.0	13626.8	121348.9	57729.2	0.0	192704.9

M BD. FT. REMOVED BY THINNING

BLOCK	TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5	TOTAL
1	0.0	0.0	0.0	14596.6	0.0	14596.6
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	3217.7	15173.1	0.0	18390.7
TOTAL	0.0	0.0	3217.7	29769.7	0.0	32987.4

PAGE TYPE 3

M BD. FT. TO BE SALVAGED IN NEXT PERIOD

BLOCK	TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5	TOTAL
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	0.0	0.0	0.0	0.0	0.0

M BD. FT. TO BE HARVESTED BY REGENERATION CUTS

BLOCK	TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5	TOTAL
1	0.0	0.0	0.0	86592.7	52597.5	139190.2
2	0.0	0.0	242.7	56487.4	27793.8	84523.9
3	0.0	0.0	0.0	68353.2	5489.9	73843.1
TOTAL	0.0	0.0	242.7	211433.3	85881.2	297557.2

HUNDREDS OF CU. FT. FROM REGENERATION CUTS

BLOCK	TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5	TOTAL
1	0.0	0.0	0.0	0.0	41976.1	41976.1
2	0.0	0.0	0.0	24504.3	30333.2	54837.5
3	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	0.0	0.0	24504.3	72309.3	96813.6

PAGE TYPE 3

M BD. FT. TO BE HARVESTED BY FINAL REMOVAL OF OVERWOOD

BLOCK	TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5	TOTAL
1	0.0	0.0	0.0	6358.7	1079.5	7438.2
2	0.0	0.0	0.0	2098.1	11837.9	13936.0
3	0.0	0.0	0.0	24127.1	23502.3	47629.4
TOTAL	0.0	0.0	0.0	32583.9	36419.7	69003.6

HUNDREDS OF CU. FT. FROM FINAL CUTS

BLOCK	TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5	TOTAL
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	0.0	0.0	0.0	0.0	0.0

ACRES OF NONCOMMERCIAL THINNING DURING NEXT PERIOD

BLOCK	TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5	TOTAL
1	8.9	12493.6	3117.9	3180.1	106.7	18907.1
2	515.6	4764.3	6512.4	191.2	0.0	11983.5
3	4266.4	5617.4	8426.1	2808.7	0.0	21118.7
TOTAL	4790.9	22875.3	18056.4	6180.0	106.7	52009.3

PAGE TYPE 3

POTENTIAL WORK LOAD AND YIELDS FOR NEXT PERIOD
BOGUS NATIONAL FOREST

ACRES OF COMMERCIAL THINNING DURING NEXT PERIOD

BLOCK	TYPE 6	TYPE 7	TYPE 8	TYPE 9	TYPE 10	TOTAL
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	4724.3	0.0	0.0	4724.3
3	0.0	0.0	0.0	1404.4	0.0	1404.4
TOTAL	0.0	0.0	4724.3	1404.4	0.0	6128.7

HUNDREDS OF CU. FT. REMOVED BY THINNING

BLOCK	TYPE 6	TYPE 7	TYPE 8	TYPE 9	TYPE 10	TOTAL
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	49134.4	0.0	0.0	49134.4
3	0.0	0.0	0.0	5666.4	0.0	5666.4
TOTAL	0.0	0.0	49134.4	5666.4	0.0	54800.8

M BD. FT. REMOVED BY THINNING

BLOCK	TYPE 6	TYPE 7	TYPE 8	TYPE 9	TYPE 10	TOTAL
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	9378.7	0.0	0.0	9378.7
3	0.0	0.0	0.0	7959.5	0.0	7959.5
TOTAL	0.0	0.0	9378.7	7959.5	0.0	17338.1

PAGE TYPE 1

M BD. FT. TO BE SALVAGED IN NEXT PERIOD

BLOCK	TYPE 6	TYPE 7	TYPE 8	TYPE 9	TYPE 10	TOTAL
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	0.0	0.0	0.0	0.0	0.0

M BD. FT. TO BE HARVESTED BY REGENERATION CUTS

BLOCK	TYPE 6	TYPE 7	TYPE 8	TYPE 9	TYPE 10	TOTAL
1	0.0	0.0	0.0	20779.7	0.0	20779.7
2	0.0	0.0	0.0	17296.3	0.0	17296.3
3	0.0	0.0	0.0	0.0	0.0	0.
TOTAL	0.0	0.0	0.0	38076.0	0.0	38076.0

HUNDREDS OF CU. FT. FROM REGENERATION CUTS

BLOCK	TYPE 6	TYPE 7	TYPE 8	TYPE 9	TYPE 10	TOTAL
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	0.0	0.0	0.0	0.0	0.0

PAGE TYPE 3

M BD. FT. TO BE HARVESTED BY FINAL REMOVAL OF OVERWOOD

BLOCK	TYPE 6	TYPE 7	TYPE 8	TYPE 9	TYPE 10	TOTAL
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	0.0	0.0	0.0	0.0	0.0

HUNDREDS OF CU. FT. FROM FINAL CUTS

BLOCK	TYPE 6	TYPE 7	TYPE 8	TYPE 9	TYPE 10	TOTAL
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	0.0	0.0	0.0	0.0	0.0

ACRES OF NONCOMMERCIAL THINNING DURING NEXT PERIOD

BLOCK	TYPE 6	TYPE 7	TYPE 8	TYPE 9	TYPE 10	TOTAL
1	0.0	26.7	0.0	0.0	0.0	26.7
2	0.0	1574.8	0.0	0.0	0.0	1574.8
3	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	1601.5	0.0	0.0	0.0	1601.5

PAGE TYPE 4

RECORD OF MANAGEMENT DECISIONS AND CURRENT CONDITIONS
BOGUS NATIONAL FOREST

NUMBER OF BLOCKS - 3 NUMBER OF COMPARTMENTS - 289

MINIMUM AGE FOR GROWING STOCK - 30 LENGTH OF CUTTING CYCLE, YEARS - 20.

MINIMUM M BD. FT. FOR GROWING STOCK - 1.5 LENGTH OF PREDICTION PERIOD, YEARS - 10.

LENGTH OF PLANNING PERIOD, YEARS - 10.

	PINE GROUP	SPRUCE GROUP
LOWEST SITE CLASS TO BE MANAGED	40.0	50.0
LENGTH OF ADJUSTMENT PERIOD, YEARS	30.0	30.0
M BD. FT. TO BE LEFT AS SEED SOURCE	4.0	0.0
CU. FT. TO BE LEFT AS SEED SOURCE	8.0	0.0
YEARS TO LEAVE OVERWOOD AS SEED SOURCE	20.0	0.0
EXPECTED DELAY IN REGENERATION, YEARS	10.0	10.0
BD. FT. GROWTH OF SHELTERWOOD, PERCENT	3.00	2.50
CU. FT. GROWTH OF SHELTERWOOD, PERCENT	2.50	2.00
STOCKING LEVEL FOR INITIAL THINNING	100.0	100.0
STOCKING LEVEL, SUBSEQUENT THINNINGS	100.0	90.0
MINIMUM COMMERCIAL CUT, M BD. FT.	1.5	1.5
MINIMUM COMMERCIAL CUT, CU. FT.	4.0	4.0

CUBIC FEET IN HUNDREDS

PAGE TYPE 5

AREAS OF TYPES IN WORKING CIRCLE
BOGUS NATIONAL FOREST

	COVER TYPE	ACRES	*		COVER TYPE	ACRES
1	PIN 0-30	22057.9	*	11	DEFOREST-B	8152.2
2	PIN 31-50	26471.2	*	12	DEFOREST-G	17509.3
3	PIN 51-100	52957.2	*	13	RECREATION	3911.1
4	PIN 101-40	68467.0	*	14	BARREN	581.6
5	PIN 141+	18622.4	*	15	BRUSHLAND	1390.2
6	SPR 0-30	1558.9	*	16	RANGE-HERB	8198.8
7	SPR 31-50	1610.4	*	17	PRIVATE	47799.4
8	SPR 51-100	4764.3	*	18		0.0
9	SPR 101-40	8438.6	*	19		0.0
10	SPR 141+	0.0	*	20		0.0
					TOTAL AREA	292490.4

PINE GROUP - 188575.7 SPRUCE GROUP - 16372.2 DEFORESTED ACRES - 25661.5

PAGE TYPE 6

TOTAL AREAS IN BLOCKS AND WORKING CIRCLE
BOGUS NATIONAL FOREST

BLOCK NO.	TOTAL ACRES	PLANTABLE ACRES FOREST SOIL			FOREST AND REGENERATING	
		BRUSHY	GRASSY	TOTAL	PINE	SPRUCE
1	103754.5	5223.4	1481.2	7204.5	68500.4	4739.0
2	104194.5	84.5	5226.5	5311.0	69162.8	8811.2
3	84541.4	2844.3	1 301.0	13145.3	50912.5	2822.0
TOTAL	292490.4	8152.2	17509.3	25661.5	188575.7	16372.2

DESIGNATIONS OF TYPES

1	PIN 0-30	*	11	DEFOREST-P
2	PIN 31-50	*	12	DEFOREST-S
3	PIN 51-100	*	13	RECREATION
4	PIN 101-40	*	14	BARREN
5	PIN 141+	*	15	BRUSHLAND
6	SPR 0-30	*	16	RANGE-HERB
7	SPR 31-50	*	17	PRIVATE
8	SPR 51-100	*	18	
9	SPR 101-40	*	19	
10	SPR 141+	*	20	

PAGE TYPE 7

VOLUMES OF BLOCKS AND WORKING CIRCLE
BOGUS NATIONAL FOREST

BLOCK NO.	TOTAL PINE WORKING GROUP			TOTAL SPRUCE WORKING GROUP			TOTAL VOLUME OF BLOCK		
	TOTAL CU. FT.	MERCH. CU. FT.	M BD. FT.	TOTAL CU. FT.	MERCH. CU. FT.	M BD. FT.	TOTAL CU. FT.	MERCH. CU. FT.	M BD. FT.
1	1476578.4	1124920.5	310747.4	145796.1	132422.6	26683.6	1622374.5	1257343.1	337431.1
2	1334102.0	1019114.2	224349.6	362130.0	[illegible]	66383.8	1696232.1	1311791.2	[illegible]
3	840874.4	647542.5	[illegible]	[illegible]	122856.1	28477.4	972174.6	770398.6	[illegible]
SUMS	3651554.8	2791577.2	741923.7	639226.4	547455.7	121544.8	4290781.1	3339532.8	[illegible]

CUBIC FEET IN HUNDREDS, BOARD FEET IN THOUSANDS

PAGE TYPE 8

TOTAL AREAS AND VOLUMES OF BLOCKS AND WORKING CIRCLE
BOGUS NATIONAL FOREST

BLOCK NO.	TYPE NO.	TOTAL ACRES	TOTAL CU. FT.	MERCH. CU. FT.	M BD. FT.	ACRES LOW SITE	NUMBER OF RECORDS
1	1	3117.9	0.0	0.0	0.0	0.0	5.
1	2	14350.3	130964.8	17865.4	0.0	0.0	15.
1	3	12706.9	264375.0	152749.9	3348.2	0.0	16.
1	4	30415.1	846810.6	741686.6	232377.5	0.0	31.
1	5	7910.2	231628.1	212618.6	75021.8	0.0	8.
1	6	1545.6	0.0	0.0	0.0	0.0	1.
1	7	35.6	937.8	523.1	23.3	0.0	2.
1	8	0.0	0.0	0.0	0.0	0.0	0.
1	9	3157.8	144858.3	131099.5	26660.4	0.0	5.
1	10	0.0	0.0	0.0	0.0	0.0	0.
1	11	5223.4	0.0	0.0	0.0	0.0	7.
1	12	1981.2	0.0	0.0	0.0	0.0	5.
2	1	8753.9	0.0	0.0	0.0	0.0	13.
2	2	6503.5	111185.6	43240.6	0.0	0.0	8.
2	3	27611.1	527984.0	382229.1	51120.6	0.0	24.
2	4	19795.2	497658.9	419830.4	120866.6	0.0	21.
2	5	6499.1	197273.5	173814.1	52362.4	0.0	6.
2	6	0.0	0.0	0.0	0.0	0.0	0.
2	7	1574.8	19122.2	0.0	0.0	0.0	1.
2	8	4764.3	192187.4	150271.3	21167.2	0.0	4.
2	9	2472.1	150820.5	142405.7	45216.5	0.0	3.
2	10	0.0	0.0	0.0	0.0	0.0	0.
2	11	845.5	0.0	0.0	0.0	0.0	2.
2	12	5226.5	0.0	0.0	0.0	0.0	8.
3	1	10186.1	0.0	0.0	0.0	0.0	12.
3	2	5617.4	93814.5	18731.1	0.0	0.0	4.
3	3	12639.2	151022.0	108683.0	10775.6	0.0	9.
3	4	18256.6	493855.5	442607.6	165230.7	1404.4	13.
3	5	4213.1	102182.4	77520.8	30820.4	0.0	3.
3	6	13.3	0.0	0.0	0.0	0.0	1.
3	7	0.0	0.0	0.0	0.0	0.0	0.
3	8	0.0	0.0	0.0	0.0	0.0	0.
3	9	2808.7	131300.2	122856.1	28477.4	0.0	2.
3	10	0.0	0.0	0.0	0.0	0.0	0.
3	11	2844.3	0.0	0.0	0.0	0.0	4.
3	12	10301.6	0.0	0.0	0.0	0.0	13.
TOTALS		230609.3	4290781.1	3339532.8	863468.5	1404.4	251.

CUBIC FEET IN HUNDREDS, BOARD FEET IN THOUSANDS

PAGE TYPE 9

DISTRIBUTION OF AREA BY SITE INDEX CLASS
BOGUS NATIONAL FOREST

BLOCK	SITE INDEX	ACRES OF PINE WORKING GROUP	ACRES OF SPRUCE WORKING GROUP	DEFORESTED ACRES
1	10	0.0	0.0	0.0
1	20	0.0	0.0	0.0
1	30	0.0	0.0	0.0
1	40	4921.3	0.0	3237.8
1	50	20563.8	40.0	2207.8
1	60	30170.6	1590.0	1759.0
1	70	12844.7	3109.0	0.0
1	80	0.0	0.0	0.0
1	90	0.0	0.0	0.0
1	100	0.0	0.0	0.0
2	10	0.0	0.0	0.0
2	20	0.0	0.0	0.0
2	30	0.0	0.0	0.0
2	40	9653.1	0.0	0.0
2	50	25876.4	1574.8	3291.8
2	60	25279.5	3242.9	222.2
2	70	8353.8	3993.6	1797.1
2	80	0.0	0.0	0.0
2	90	0.0	0.0	0.0
2	100	0.0	0.0	0.0
3	10	0.0	0.0	0.0
3	20	0.0	0.0	0.0
3	30	1404.4	0.0	0.0
3	40	12857.0	0.0	0.0
3	50	11234.9	0.0	5706.3
3	60	15505.7	0.0	4453.1
3	70	9910.5	2822.0	2986.5
3	80	0.0	0.0	0.0
3	90	0.0	0.0	0.0
3	100	0.0	0.0	0.0
TOTAL		188575.7	16372.2	25661.5

PAGE TYPE 10

YIELDS PER ACRE OF MANAGED, EVEN-AGED STANDS BASED ON PREDETERMINED STANDARDS FOR
SITE INDEX 70., 20.-YEAR CUTTING CYCLE, DENSITY LEVEL 100.

WORKING GROUP - PINE

	ENTIRE STAND BEFORE AND AFTER THINNING							PERIODIC CUT AND MORTALITY				
STAND AGE (YEARS)	TREES NO.	BASAL AREA SQ. FT.	AVERAGE D.B.H. IN.	AVERAGE HEIGHT FT.	TOTAL VOLUME CU. FT.	MERCHANT-ABLE VOLUME CU. FT.	SAWTIMBER VOLUME M BD. FT.	TREES NO.	BASAL AREA SQ. FT.	TOTAL VOLUME CU. FT.	MERCHANT-ABLE VOLUME CU. FT.	SAWTIMBER VOLUME M BD. FT.
30.	1000	126	4.8	25	1245	312.	0.000					
30.	373	68	5.8	27	750	312.	0.000	627	58	495	0.	0.000
40.	370	96	6.9	36	1399	973.	0.000					
50.	365	121	7.8	44	2203	1789.	1.400					
50.	239	94	8.5	45	1748	1520.	1.400	126	27	455	269.	0.000
60.	237	114	9.4	51	2413	2203.	4.170					
70.	235	133	10.2	58	3229	2998.	8.250					
70.	154	100	10.9	59	2468	2308.	7.270	81	33	761	690.	.980
80.	154	117	11.8	65	3232	3038.	12.450					
90.	154	133	12.6	69	4007	3781.	15.350					
90.	104	100	13.3	70	3055	2891.	12.210	50	33	952	890.	3.140
100.	104	114	14.2	74	3717	3530.	15.950					
110.	104	129	15.1	78	4432	4221.	20.240					
110.	73	99	15.8	78	3437	3280.	16.130	31	30	995	941.	4.110
120.	73	112	16.8	82	4058	3883.	20.130					
130.	73	125	17.7	84	4671	4479.	24.240					
130.	54	100	18.4	85	3759	3609.	19.900	19	25	912	870.	4.340
140.	54	111	19.4	87	4309	4146.	23.800					
150.	54	121	20.3	89	4844	4668.	27.720					

PAGE TYPE 11

GROWING STOCK OF MANAGED, REGULATED, EVEN-AGED STANDS
SITE INDEX 70., 20.-YEAR CUTTING CYCLE
DENSITY LEVEL- 100. AND 100.

WORKING GROUP - PINE

VOLUMES PRESENT PER ACRE AT END OF EACH YEAR

MERCHANTABLE CUBIC FEET

	YEAR									
DECADE	0	1	2	3	4	5	6	7	8	9
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	312.0	378.1	444.2	510.3	576.4	642.5	708.6	774.7	840.8	906.9
4	973.0	1054.6	1136.2	1217.8	1299.4	1381.0	1462.6	1544.2	1625.8	1707.4
5	1520.0	1588.3	1656.6	1724.9	1793.2	1861.5	1929.8	1998.1	2066.4	2134.7
6	2203.0	2282.5	2362.0	2441.5	2521.0	2600.5	2680.0	2759.5	2839.0	2918.5
7	2308.0	2381.0	2454.0	2527.0	2600.0	2673.0	2746.0	2819.0	2892.0	2965.0
8	3038.0	3112.3	3186.6	3260.9	3335.2	3409.5	3483.8	3558.1	3632.4	3706.7
9	2891.0	2954.9	3018.8	3082.7	3146.6	3210.5	3274.4	3338.3	3402.2	3466.1
10	3530.0	3599.1	3668.2	3737.3	3806.4	3875.5	3944.6	4013.7	4082.8	4151.9
11	3280.0	3340.3	3400.6	3460.9	3521.2	3581.5	3641.8	3702.1	3762.4	3822.7
12	3883.0	3942.6	4002.2	4061.8	4121.4	4181.0	4240.6	4300.2	4359.8	4419.4
13	3609.0	3662.7	3716.4	3770.1	3823.8	3877.5	3931.2	3984.9	4038.6	4092.3
14	4146.0	4198.2	4250.4	4302.6	4354.8	4407.0	4459.2	4511.4	4563.6	4615.8
15	4668.0									

THOUSANDS OF BOARD FEET

0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	.140	.280	.420	.560	.700	.840	.980	1.120	1.260
5	1.400	1.677	1.954	2.231	2.508	2.785	3.062	3.339	3.616	3.893
6	4.170	4.578	4.986	5.394	5.802	6.210	6.618	7.026	7.434	7.842
7	7.270	7.788	8.306	8.824	9.342	9.860	10.378	10.896	11.414	11.932
8	12.450	12.740	13.030	13.320	13.610	13.900	14.190	14.480	14.770	15.060
9	12.210	12.584	12.958	13.332	13.706	14.080	14.454	14.828	15.202	15.576
10	15.950	16.379	16.808	17.237	17.666	18.095	18.524	18.953	19.382	19.811
11	16.130	16.530	16.930	17.330	17.730	18.130	18.530	18.930	19.330	19.730
12	20.130	20.541	20.952	21.363	21.774	22.185	22.596	23.007	23.418	23.829
13	19.900	20.290	20.680	21.070	21.460	21.850	22.240	22.630	23.020	23.410
14	23.800	24.192	24.584	24.976	25.368	25.760	26.152	26.544	26.936	27.328
15	27.720									

PAGE TYPE 12

DISTRIBUTION OF AREA AND GROWING STOCK GOALS

FOR SITE INDEX CLASS- 70., ROTATION- 130., AND 35532.6 ACRES OF THIS SITE CLASS AND GROUP

WORKING GROUP - PINE

AGE CLASS	ACRES IN CLASS	HUNDREDS OF CU. FT.	M BD. FT.
1- 10	2733.3	30339.4	16017.0
11- 20	2733.3	0.0	0.0
21- 30	2733.3	852.8	0.0
31- 40	2733.3	18464.7	0.0
41- 50	2733.3	38126.5	0.0
51- 60	2733.3	51813.4	7990.7
61- 70	2733.3	70279.5	17263.4
71- 80	2733.3	74058.2	27658.1
81- 90	2733.3	91774.0	37530.7
91-100	2733.3	88625.2	38995.7
101-110	2733.3	104300.6	48921.6
111-120	2733.3	98716.5	50101.0
121-130	2733.3	24872.9	12737.1
131-140	0.0	0.0	0.0
TOTALS	35532.6	692223.7	257215.3

PAGE TYPE 13

GROWING STOCK GOALS FOR WORKING CIRCLE

WORKING GROUP - PINE

BOGUS NATIONAL FOREST

SITE CLASS	ACRES	ROTATION AGE	CU. FT. TO BD. FT. LIMIT	CU. FT. TO ROTATION AGE	M BD. FT. ABOVE BD. FT. LIMIT
40.	30459.6	110.	64476.	255228.	64029.
50.	68066.4	130.	122508.	890443.	284131.
60.	77017.4	130.	120470.	1256453.	445646.
70.	35532.6	130.	57444.	692224.	257215.
TOTALS	212480.4		364898.	3094347.	1051022.

CUBIC FEET IN HUNDREDS. TOTAL AREA INCLUDES ANY LOW SITE ACRES INCORRECTLY CLASSED AS OPERABLE TYPES.

PAGE TYPE 14

CONVERSION OF AREAS TO STANDARD ACRES

WORKING GROUP - [illegible]

BEAR NATIONAL FOREST

SITE INDEX CLASS	TOTAL YIELD PER ACRE M BD. FT.	ACRES IN SITE CLASS	REDUCTION FACTOR	AREA IN STANDARD ACRES	EQUIVALENT OF STANDARD ACRE IN SITE ACRES
40.	8.5	30459.6	.49679	15131.7	2.01294
50.	17.1	68066.4	1.00000	68066.4	1.00000
60.	26.6	77017.4	1.55523	119779.8	.64299
70.	31.5	35532.6	1.84344	65505.4	.54240
TOTALS		212480.4		268374.2	

SITE INDEX CLASS	TOTAL YIELD PER ACRE CU. FT.	ACRES IN SITE CLASS	REDUCTION FACTOR	AREA IN STANDARD ACRES	EQUIVALENT OF STANDARD ACRE IN SITE ACRES
40.	22.2	30459.6	.53329	16243.7	1.87517
50.	41.6	68066.4	1.00000	68066.4	1.00000
60.	57.5	77017.4	1.38308	106521.3	.72302
70.	70.0	35532.6	1.68229	59776.1	.59443
TOTALS		212480.4		250607.5	

PAGE TYPE 10

YIELDS PER ACRE OF MANAGED, EVEN-AGED STANDS BASED ON PREDETERMINED STANDARDS FOR SITE INDEX 70., 20.-YEAR CUTTING CYCLE, DENSITY LEVEL 90.

WORKING GROUP - [illegible]

STAND AGE (YEARS)	ENTIRE STAND BEFORE AND AFTER THINNING: TREES NO.	BASAL AREA SQ. FT.	AVERAGE D.B.H. IN.	AVERAGE HEIGHT FT.	TOTAL VOLUME CU. FT.	MERCHANTABLE VOLUME CU. FT.	SAWTIMBER VOLUME M BD. FT.	PERIODIC CUT AND MORTALITY: TREES NO.	BASAL AREA SQ. FT.	TOTAL VOLUME CU. FT.	MERCHANTABLE VOLUME CU. FT.	SAWTIMBER VOLUME M BD. FT.
30.	1556	110	3.6	28	1525	0.	0.000					
30.	472	50	4.4	28	704	0.	0.000	1078	60	[illegible]	[illegible]	[illegible]
40.	467	[illegible]	5.6	35	1434	556.	0.000					
50.	465	110	6.6	40	2235	1492.	0.000					
50.	250	74	7.6	40	1598	1309.	0.000	215	31	637	183.	[illegible]
60.	248	100	8.6	47	2356	2135.	2.150					
70.	247	122	9.5	53	3265	3031.	5.760					
70.	156	90	10.3	53	2408	2284.	5.760	91	32	857	747.	[illegible]
80.	156	109	11.3	58	3150	3013.	10.330					
80.	156	127	12.2	63	3982	3772.	14.750					
80.	98	90	13.0	63	2845	2702.	11.260	58	37	1137	1070.	3.490
100.	98	127	14.1	69	3534	3366.	14.970					
110.	98	126	15.1	69	4238	4045.	18.000					
110.	66	90	15.8	69	3129	2991.	14.240	32	37	1109	1054.	4.590
120.	66	103	16.9	72	3715	3558.	17.450					
130.	66	117	18.	74	4348	4172.	21.270					
130.	49	97	18.5	74	3345	3211.	16.210	17	20	1003	961.	4.770
140.	49	102	19.7	76	3695	3546.	19.160					
150.	49	113	21.0	78	4445	4268.	22.060					

PAGE TYPE 11

GROWING STOCK OF MANAGED, REGULATED, EVEN-AGED STANDS
SITE INDEX 70., 20.-YEAR CUTTING CYCLE
DENSITY LEVEL- 100. AND 90.

WORKING GROUP - SPRUCE

VOLUMES PRESENT PER ACRE AT END OF EACH YEAR

MERCHANTABLE CUBIC FEET

DECADE	YEAR 0	1	2	3	4	5	6	7	8	9
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	55.2	110.4	165.6	220.8	276.0	331.2	386.4	441.6	496.8
4	552.0	646.0	740.0	834.0	928.0	1022.0	1116.0	1210.0	1304.0	1398.0
5	1309.0	1391.6	1474.2	1556.8	1639.4	1722.0	1804.6	1887.2	1969.8	2052.4
6	2135.0	2224.6	2314.2	2403.8	2493.4	2583.0	2672.6	2762.2	2851.8	2941.4
7	2284.0	2356.9	2429.8	2502.7	2575.6	2648.5	2721.4	2794.3	2867.2	2940.1
8	3013.0	3088.9	3164.8	3240.7	3316.6	3392.5	3468.4	3544.3	3620.2	3696.1
9	2702.0	2768.4	2834.8	2901.2	2967.6	3034.0	3100.4	3166.8	3233.2	3299.6
10	3366.0	3433.9	3501.8	3569.7	3637.6	3705.5	3773.4	3841.3	3909.2	3977.1
11	2991.0	3047.7	3104.4	3161.1	3217.8	3274.5	3331.2	3387.9	3444.6	3501.3
12	3558.0	3619.4	3680.8	3742.2	3803.6	3865.0	3926.4	3987.8	4049.2	4110.6
13	3211.0	3264.5	3318.0	3371.5	3425.0	3478.5	3532.0	3585.5	3639.0	3692.5
14	3746.0	3799.4	3852.8	3906.2	3959.6	4013.0	4066.4	4119.8	4173.2	4226.6
15	4280.0									

THOUSANDS OF BOARD FEET

0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	.215	.430	.645	.860	1.075	1.290	1.505	1.720	1.935
6	2.150	2.511	2.872	3.233	3.594	3.955	4.316	4.677	5.038	5.399
7	5.760	6.217	6.674	7.131	7.588	8.045	8.502	8.959	9.416	9.873
8	10.330	10.772	11.214	11.656	12.098	12.540	12.982	13.424	13.866	14.308
9	11.260	11.631	12.002	12.373	12.744	13.115	13.486	13.857	14.228	14.599
10	14.970	15.353	15.736	16.119	16.502	16.885	17.268	17.651	18.034	18.417
11	14.240	14.561	14.882	15.203	15.524	15.845	16.166	16.487	16.808	17.129
12	17.450	17.795	18.140	18.485	18.830	19.175	19.520	19.865	20.210	20.555
13	16.210	16.505	16.800	17.095	17.390	17.685	17.980	18.275	18.570	18.865
14	19.160	19.450	19.740	20.030	20.320	20.610	20.900	21.190	21.480	21.770
15	22.060									

PAGE TYPE 12

DISTRIBUTION OF AREA AND GROWING STOCK GOALS

FOR SITE INDEX CLASS- 70., ROTATION- 110., AND 10284.5 ACRES OF THIS SITE CLASS AND GROUP

WORKING GROUP - SPRUCE

AGE CLASS	ACRES IN CLASS	HUNDREDS OF CU. FT.	M BD. FT.
0	935.0		
1- 10	935.0	0.0	0.0
11- 20	935.0	0.0	0.0
21- 30	935.0	0.0	0.0
31- 40	935.0	2838.5	0.0
41- 50	935.0	9823.5	0.0
51- 60	935.0	16486.0	683.4
61- 70	935.0	23870.2	3866.5
71- 80	935.0	25103.0	7735.3
81- 90	935.0	31072.6	11604.6
91-100	935.0	28676.8	12435.3
101-110	0.0	0.0	0.0
111-120	0.0	0.0	0.0
TOTALS	10284.5	137870.6	36325.2

AGE CLASS ZERO REPRESENTS CLEARCUT ACRES NOT YET REFORESTED BECAUSE OF DELAY OF 10. YEARS EXPECTED AFTER SCHEDULED REGENERATION CUTTING.

PAGE TYPE 13

GROWING STOCK GOALS FOR WORKING CIRCLE

WORKING GROUP - SPRUCE

BOGUS NATIONAL FOREST

SITE CLASS	ACRES	ROTATION AGE	CU. FT. TO MD. FT. LIMIT	CU. FT. TO ROTATION AGE	M BD. FT. ABOVE CU. FT. LIMIT
50.	2429.3	90.	7269.	11851.	641.
60.	5205.6	110.	13708.	55014.	11468.
70.	10284.5	110.	21627.	137871.	36425.
TOTALS	18128.9		42602.	204765.	48435.

CUBIC FEET IN HUNDREDS. TOTAL AREA INCLUDES ANY LOW SITE ACRES INCLUDED IN CLASSES AS SPERABLE TYPES.

PAGE TYPE 14

CONVERSION OF AREAS TO STANDARD ACRES

WORKING GROUP - SPRUCE

BOGUS NATIONAL FOREST

SITE INDEX CLASS	TOTAL YIELD PER ACRE M BD. FT.	ACRES IN SITE CLASS	REDUCTION FACTOR	AREA IN STANDARD ACRES	EQUIVALENT OF STANDARD ACRE IN SITE ACRES
50.	5.1	2429.3	.35090	852.4	2.84980
60.	14.4	5205.6	1.00000	5205.6	1.00000
70.	22.3	10284.5	1.54577	15897.4	.64693
TOTALS		18128.9		21955.5	

SITE INDEX CLASS	TOTAL YIELD PER ACRE CU. FT.	ACRES IN SITE CLASS	REDUCTION FACTOR	AREA IN STANDARD ACRES	EQUIVALENT OF STANDARD ACRE IN SITE ACRES
50.	23.4	2429.3	.91566	1252.7	1.93926
60.	45.3	5205.6	1.00000	5205.6	1.00000
70.	58.6	10284.5	1.29290	13296.8	.77346
TOTALS		18128.9		19755.1	

APPENDIX 3

Alternative Outputs

Source programs for MAPS and AREA1 are listed below. Each program is followed by the type 5 pages produced. Subroutine MAPS produces two type 5 pages for each compartment if maps are desired, and a single type 5 page per compartment if map output is suppressed. Type 6 pages produced by MAPS and AREA1 are not reproduced because they do not differ in format from the page type 6 of AREA2 in Appendix 2.

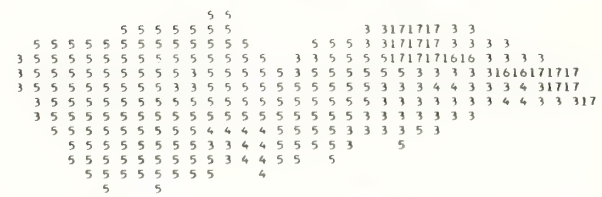
```
      SUBROUTINE MAPS
C
C TO COMPUTE AREAS FROM TYPE AND SUBCOMPARTMENT MAPS.
C
      COMMON AREAG(3,15),ACBAR(5),ACSI(3,5,10),ACSP(3,5),ALLCF(3,10),AMC
     1AG(3,15),ANCUT(3,10),ARBK(5),AREA(3,10),BARSI(5,10),BFAGE(3,15),BF
     2TH(5,12),BFMRCH,CFAGE(3,15),CFBF(3,10),CMTH(5,12),COMBF(3),COMCU,C
     3UTA(5,12),CUTB(5,12),CYCL,DATE(3),DLEV(3),FINL(3),FORET(3),GRBD(3,
     45,15),GRMC(3,5,15),GROWB(3),GROWC(3),GVLBF(3),GVLCU(3),MIN,NBK,NCM
     5P,NSBK(5),NSI(3),NSUB,OPEN(5,12),POOR(3),PRET,RAGE(3,10),RINT,ROTA
     6,SARETY(5,20),SARSP(3),SBARB,SBARE,SBARG,SBF(3),SHELT(3),SHWD(3),S
     7LAND,SLVG(5,12),SMC(3),SMSP(3),STYP(20),SUBBF(3,10),SUBCF(3,10),SU
     8MCF(3),THIN(3),TMBR,TMPO,TYPNM(20),DELAY(3),ACFNL(3,5,15),ACRGN(3,
     95,15),TIME,PDCFR(5,12),PDCFN(5,12),OPCU(3),FNCU(3),CUINT(3),ACINT(
     13),FNBD(3),BFINT(3),OPBD(3),TEM,MNK,KNO,FCTR(2),PROD(2),KAK,VDM(2)
     2,ADJ(3),ALOWC(3),ALWBF(3),BDMAI(3),CUMAI(3),PAIBD(3),PAICU(3),DBHO
     3,DENO,REST,DBHT,BAST,NWGP,HELP(5,12),BA(2)
C
      DIMENSION KSUB(36,36),KTYP(36,36),ARESC(30),ARETY(20),CVR(20),SURT
     1Y(30),UNIT(30),GRUP(3)
      READ (5,1) MAP,SCALE
    1 FORMAT (I4,F6.4)
C
C REPEAT LOOP FOR EACH COMPARTMENT.
C
      DO 200 KOL=1,NCMP
C
C INITIALIZE VARIABLES APPLICABLE TO A COMPARTMENT.
C
      DO 4 I=1,30
      ARESC(I) = 0.0
      SURTY(I) = 0.0
    4 UNIT(I) = 0.0
      DO 5 I=1,3
    5 GRUP(I) = 0.0
      DO 6 I=1,36
      DO 6 J=1,36
      KSUB(I,J) = 0
    6 KTYP(I,J) = 0
      DO 7 I=1,20
      ARETY(I) = 0.0
      CVR(I) = 0.0
    7 CONTINUE
      ARECP = 0.0
      BARE = 0.0
      SARSC = 0.0
C
C READ DATA FOR A COMPARTMENT.
C LOGICAL UNIT 3 HOLDS THE TAPE WITH MAPS IF TAPE IS USED.
C
      READ (3,11) KBK,KOMP,NROW
   11 FORMAT (3I4)
      READ (3,12) ((KTYP(I,J),J=1,36),I=1,NROW)
```

```
      DIMENSION [illegible]
      [illegible]

C     [illegible] TYPE AREAS AND TOTAL AREA.

      [illegible]
      [illegible]
      IF(KTYP([illegible]) .LT. [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]

C     [illegible] AREA OF A SUBCOMPARTMENT AREA AND ITS [illegible] AREA.

      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]

C     [illegible] SUBCOMPARTMENT AREAS AND TYPES.

      [illegible]
      IF([illegible] .LT. [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
   31 CONTINUE
   32 CONTINUE
      [illegible]
      [illegible]
      [illegible]

C     [illegible] NUMBER OF SUBCOMPARTMENT TYPES IN EACH COMPARTMENT.
C     [illegible] PRINT ROWS FOR EXISTING SUBCOMPARTMENT AREAS.

      [illegible]
      MAX = I
      IF(AREA([illegible]) .[illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]

C     [illegible] SUBCOMPARTMENT MAPS, IF [illegible].

      [illegible]

C     [illegible] ARE [illegible] DISPLAY [illegible] AND LIGHT SATISFY. [illegible] WILL
C     VARY WITH MODEL OF COMPUTER.

      [illegible]
      [illegible]
      IF(KTYP(I,J) .LT. 1) GO TO 41
      IF(KTYP(I,J) .LE. 9) GO TO 42
      [illegible]
      [illegible]
      [illegible]
      IF(KTYP(I,J) .GT. 9) GO TO 40
      [illegible]
   41 KTYP(I,J) = 5555B
      GO TO 44
   42 KTYP(I,J) = KTYP(I,J) + 2907
      [illegible]
      [illegible]
      KTYP(I,J) = KTYP(I,J) + [illegible]
      [illegible]
      [illegible]
      DO 49 J=1,36
      IF(KSUB(I,J) .LT. 1) GO TO 46
      IF(KSUB(I,J) .LE. 9) GO TO 47
      [illegible]
      [illegible]
      KSUB(I,J) = KSUB(I,J) - 10
      [illegible]
      [illegible]
   47 [illegible]
      [illegible]
   48 KSUB(I,J) = KSUB(I,J) + 27
      [illegible]
   49 CONTINUE

C  PRINT PAGE TYPE 5 - TYPE AND SUBCOMPARTMENT MAPS AND AREAS.

C  PRINT TYPE MAP AND TYPE AREAS.

      [illegible]
```

```
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
```

```
299 FORMAT (1H1,////,59X,11HPAGE TYPE 6)
    WRITE (6,300)
300 FORMAT (1HO,44X,40HTOTAL AREAS OF BLOCKS AND WORKING CIRCLE)
    WRITE (6,301) (FORET(I),I=1,3)
301 FORMAT (1H ,53X,3A8)
    WRITE (6,302)
302 FORMAT (1HO,//,5X,5HBLOCK,10X,5HTOTAL,8X,6HNUMBER,8X,41H------ PLA
   1NTABLE ACRES FOREST SOIL ------,16X,23HFOREST AND REGENERATING)
    WRITE (6,303)
303 FORMAT (1H ,5X,3HNO.,11X,5HACRES,7X,8HSUBCOMPT,7X,6HBRUSHY,12X,6HG
   1RASSY,12X,5HTOTAL,16X,4HPINE,13X,6HSPRUCE,//)
    DO 305 I=1,NBK
    WRITE (6,304)I,ARBK(I),NSBK(I),SARETY(I,11),SARETY(I,12),ACRAR(I),
   1ACSP(1,I),ACSP(2,I)
304 FORMAT (1HO,5X,I2,8X,F10.1,7X,I5,6X,F10.1,8X,F10.1,7X,F10.1,11X,F1
   10.1,8X,F10.1)
305 CONTINUE
    WRITE (6,306) SLAND,NSUB,SBARB,SBARG,SBARE,SMSP(1),SMSP(2)
306 FORMAT (1HO,//,5X,5HTOTAL,6X,F10.1,7X,I5,6X,F10.1,8X,F10.1,7X,F10.
   11,11X,F10.1,8X,F10.1)
    WRITE (6,307)
307 FORMAT (1HO,///,55X,21HDESIGNATIONS OF TYPES)
    DO 309 I=1,10
    J = I + 10
    WRITE (6,308) I,TYPNM(I),J,TYPNM(J)
308 FORMAT (1HO,43X,I2,4X,A10,6X,1H*,6X,I2,4X,A10)
309 CONTINUE
    RETURN
    END
```


BOGUS NATIONAL FOREST — TYPE MAP OF COMPARTMENT NO. 206 — BLOCK NO. 3



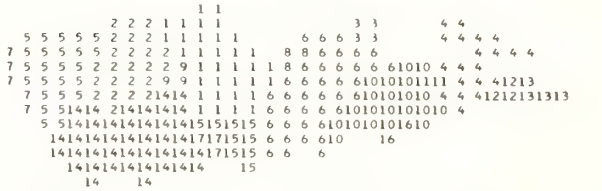
	COVER TYPE	ACRES	*		COVER TYPE	ACRES
1	PIN 0-30	0.0	*	11	DEFOREST-B	0.0
2	PIN 31-50	0.0	*	12	DEFOREST-G	0.0
3	PIN 51-100	280.0	*	13	RECREATION	0.0
4	PIN 101-40	62.2	*	14	BARREN	0.0
5	PIN 141+	742.2	*	15	BRUSHLAND	0.0
6	SPR 0-30	0.0	*	16	RANGE-HERB	17.8
7	SPR 31-50	0.0	*	17	PRIVATE	66.7
8	SPR 51	0.0	*	18		0.0
9	SPR 101-40	0.0	*	19		0.0
10	SPR 141+	0.0	*	20		0.0

TOTAL AREA 1168.9

ACRES IN WORKING GROUP
PINE GROUP - 1084.4
SPRUCE GROUP - 0.0

DEFORESTED ACRES - 0.0

BOGUS NATIONAL FOREST — SUBCOMPARTMENT MAP OF COMPARTMENT NO. 206 — BLOCK NO. 3



SUBCOMP.	COVER TYPE	ACRES	*	SUBCOMP.	COVER TYPE	ACRES
1	5. PIN 141+	151.1	*	10	3. PIN 51-100	93.3
2	5. PIN 141+	106.7	*	11	4. PIN 101-40	8.9
3	3. PIN 51-100	17.8	*	12	4. PIN 101-40	13.3
4	3. PIN 51-100	88.9	*	13	3. PIN 51-100	17.8
5	5. PIN 141+	111.1	*	14	5. PIN 141+	186.7
6	5. PIN 141+	177.8	*	15	4. PIN 101-40	40.0
7	3. PIN 51-100	22.2	*	16	5. PIN 141+	8.9
8	3. PIN 51-100	13.3	*	17	3. PIN 51-100	13.3
9	3. PIN 51-100	13.3	*			

TOTAL AREA 1084.4

ACRES IN WORKING GROUP
PINE GROUP - 1084.4
SPRUCE GROUP - 0.0

DEFORESTED ACRES - 0.0

PAGE TYPE 5

[illegible] NATIONAL FOREST TYPE AREAS OF COMPARTMENT NO. 206 BLOCK NO. 3

	COVER TYPE	ACRES	*		COVER TYPE	ACRES
1	PIN 0-30	0.0	*	11	DEFOREST-R	0.0
2	PIN 31-50	0.0	*	12	DEFOREST-G	0.0
3	PIN 51-100	280.0	*	13	RECREATION	0.0
4	PIN 101-40	62.2	*	14	BARREN	0.0
5	PIN 141+	742.2	*	15	BRUSHLAND	0.0
6	SPR 0-30	0.0	*	16	RANGE-HERB	17.8
7	SPR 31-50	0.0	*	17	PRIVATE	66.7
8	SPR 51	0.0	*	18		0.0
9	SPR 101-40	0.0	*	19		0.0
10	SPR 141+	0.0	*	20		0.0

TOTAL AREA 1168.7

[illegible] NATIONAL FOREST SUBCOMPARTMENTS OF COMPARTMENT NO. 206 BLOCK NO. 3

SUBCOMP.	COVER TYPE	ACRES	*	SUBCOMP.	COVER TYPE	ACRES
1	5. PIN 141+	151.1	*	10	3. PIN 51-100	73.3
2	5. PIN 141+	106.7	*	11	4. PIN 101-40	8.9
3	4. PIN 101-100	17.8	*	12	4. PIN 101-40	13.3
4	3. PIN 51-100	88.9	*	13	3. PIN 51-100	17.8
5	5. PIN 141+	111.1	*	14	5. PIN 141+	186.7
6	5. PIN 141+	177.8	*	15	4. PIN 101-40	40.0
7	3. PIN 51-100	22.2	*	16	5. PIN 141+	8.9
8	3. PIN 51-100	13.3	*	17	3. PIN 51-100	13.3
9	3. PIN 51-100	13.3	*			

TOTAL AREA 1084.4

ACRES IN WORKING GROUP
PINE GROUP - 1084.4
SPRUCE GROUP - 0.0

DEFORESTED ACRES - 0.0

```
      SUBROUTINE AREA1
C
C TO COMPUTE AREAS FOR WORKING CIRCLE FROM TOTAL AREA OF EACH TYPE IN
C EACH COMPARTMENT.
C
      COMMON AREAG(3,15),ACBAR(5),ACSI(3,5,10),ACSP(3,5),ALLCF(3,10),AMC
     1AG(3,15),ANCUT(3,10),ARBK(5),AREA(3,10),BAPSI(5,10),BFAGE(3,15),BF
     2TH(5,12),BFMRCH,CFAGE(3,15),CFBF(3,10),CMTH(5,12),COMBF(3),COMCU,C
     3UTAI(5,12),CUTB(5,12),CYCL,DATE(3),DLEV(3),FINL(3),FORET(3),GRBD(3,
     45,15),GRVC(3,5,15),GRDWB(3),GRDWC(3),GVLBF(3),GVLCU(3),MIN,NBK,NCM
     5P,NSBK(5),NSI(3),NSUP,OPEN(5,12),POOR(3),PRET,RAGE(3,10),RINT,ROTA
     6,SARETY(5,20),SARSP(3),SBARB,SBARE,SBARG,SBF(3),SHELT(3),SHWD(3),S
     7LAND,SLVG(5,12),SMCF(3),SMSP(3),STYP(20),SUBBF(3,10),SUBCF(3,10),SU
     8MCF(3),THIN(3),TMBR,TMPO,TYPNM(20),DELAY(3),ACENL(3,5,15),ACRGN(3,
     95,15),TIME,PDCFR(5,12),PUCFN(5,12),OPCU(3),ENCU(3),CUINT(3),ACINT(
     13),ENBD(3),REINT(3),OPBD(3),TEM,MNK,KNJ,FCTR(2),PROD(2),KAK,VOM(2)
     2,ADJ(3),ALWBC(3),ALWBF(3),BOMAI(3),CUMAI(3),PAIBD(3),PAICU(3),DBHO
     3,DENO,REST,OBHT,BAST,NWGP,HELP(5,12),BA(2)
C
      DIMENSION ARETY(20),GRUP(3)
      KOUNT = 0
      DO 24 K=1,NCMP
C
C INITIALIZE VARIABLES APPLICABLE TO A COMPARTMENT.
C
      ARECP = 0.0
      BARE = 0.0
      DO 1 I=1,3
    1 GRUP(I) = 0.0
C
C READ AREA OF EACH TYPE, ONE COMPARTMENT AT A TIME.
C
      READ (5,5) KBK,KOMP
    5 FORMAT (2I4)
      READ (5,6) (ARETY(I),I=1,20)
    6 FORMAT (10F8.1)
C
C SUM AREAS OF TYPES TO GET COMPARTMENT AND BLOCK TOTALS.
C
      DO 15 I=1,20
      SARETY(KBK,I) = SARETY(KBK,I) + ARETY(I)
      ARECP = ARECP + ARETY(I)
   15 CONTINUE
      DO 16 I=1,5
      J = I + 5
      GRUP(1) = GRUP(1) + ARETY(I)
      GRUP(2) = GRUP(2) + ARETY(J)
   16 CONTINUE
      BARE = ARETY(11) + ARETY(12)
      ACBAR(KBK) = ACBAR(KBK) + BARE
      DO 17 I=1,NWGP
   17 ACSP(I,KBK) = ACSP(I,KBK) + GRUP(I)
      ARBK(KBK) = ARBK(KBK) + ARECP
C
C PRINT PAGE TYPE 5 - AREAS OF TYPES AND WORKING GROUPS BY COMPARTMENT.
C KOUNT CONTROLS PRINTER TO GET 3 COMPARTMENTS PER PAGE.
C
      KOUNT = KOUNT + 1
      IF(KOUNT .GT. 1) GO TO 21
      WRITE (6,19)
   19 FORMAT (1H1,7,62X,11HPAGE TYPE 5)
      WRITE (6,20) (FORET(I),I=1,3),KOMP,KBK
   20 FORMAT (1HO,6X,3A8,18X,29HTYPE AREAS OF COMPARTMENT NO.,I4,24X,9HB
     1LOCK NO.,I2)
      GO TO 23
   21 WRITE (6,22) (FORET(I),I=1,3),KOMP,KBK
   22 FORMAT (1HO,7,7X,3A8,18X,29HTYPE AREAS OF COMPARTMENT NO.,I4,24X,9
     1HBLOCK NO.,I2)
   23 WRITE (6,4)
    4 FORMAT (1HO,31X,10HCOVER TYPE,9X,5HACRES,4X,1H*,7X,10HCOVER TYPE,9
     1X,5HACRES,/)
      DO 26 I=1,10
      J = I + 10
      WRITE (6,25) I,TYPNM(I),ARETY(I),J,TYPNM(J),ARETY(J)
   25 FORMAT (1H ,28X,I2,2X,A10,4X,F9.1,4X,1H*,4X,I2,2X,A10,4X,F9.1)
   26 CONTINUE
      WRITE (6,27) ARECP
   27 FORMAT (1HO,70X,10HTOTAL AREA,2X,F9.1)
      WRITE (6,28) GRUP(1),GRUP(2),BARE
   28 FORMAT (1HO,18X,12HPINE GROUP -,F9.1,8X,14HSPRUCE GROUP -,F9.1,5X,
     11HDEFORESTED ACRES -,F9.1)
      IF(KOUNT .GE. 3) KOUNT =
   24 CONTINUE
C
C GET WORKING CIRCLE TOTALS FROM BLOCK TOTALS.
C
      DO 40 I=1,NBK
      DO 40 J=1,20
   40 STYP(J) = STYP(J) + SARETY(I,J)
      DO 41 I=1,NBK
      SBARB = SBARB + SARETY(I,11)
      SBARG = SBARG + SARETY(I,12)
      SLAND = SLAND + ARBK(I)
      DO 41 I=1,NWGP
      SMSP(J) = SMSP(J) + ACSP(J,I)
   41 CONTINUE
      SBARE = SBARB + SBARG
C
C PRINT PAGE TYPE 6 - SUMMARY OF AREAS BY ALL 3 NAT. W.RKING CIRCLE.
C
      WRITE (6,59)
   59 FORMAT (1H1,////,59X,11HPAGE TYPE 6)
      WRITE (6,60)
   60 FORMAT (1HO,44X,40HTOTAL AREAS OF BLOCKS AND WORKING CIRCLE)
      WRITE (6,61) (FORET(I),I=1,3)
   61 FORMAT (1H ,53X,3A8)
```

```
   WRITE (6,62)
62 FORMAT (1HO,//,4X,5HBLOCK,10X,5HTOTAL,14X,44H****** PLANTABLE ACRE
  1S FOREST SOIL *********,19X,23HFOREST AND REGENERATING)
   WRITE (6,63)
63 FORMAT (1H ,4X,3HNO.,11X,5HACRES,14X,6HBRUSHY,13X,6HGRASSY,14X,5HT
  1OTAL,19X,4HPINE,13X,6HSPRUCE,//)
   DO 65 I=1,NBK
   WRITE (6,64) I,ARBK(I),SARETY(I,11),SARETY(I,12),ACBAR(I),ACSP(I,1
  1),ACSP(2,I)
64 FORMAT (1HO,4X,I2,8X,F10.1,10X,F10.1,9X,F10.1,9X,F10.1,13X,F10.1,9
  1X,F10.1)
65 CONTINUE
```

```
   WRITE (6,66) SEAND,SPARB,SPARG,SHARE,SMSP(1),SMSP(2)
66 FORMAT (1H ,//,4X,5HTOTAL,4X,F10.1,10X,F10.1,9X,F10.1,9X,F10.1,13X
  1,F10.1,9X,F10.1)
   WRITE (6,67)
67 FORMAT (1H ,///,5X,21HDESIGNATIONS OF TYPES)
   DO 69 I=1,10
   J = I + 10
   WRITE (6,68) I,TYPNM(I),J,TYPNM(J)
68 FORMAT (1HO,43X,I2,4X,A10,6X,1H*,6X,I2,4X,A10)
69 CONTINUE
   RETURN
   END
```

PAGE TYPE 5

BOGUS NATIONAL FOREST — TYPE AREAS OF COMPARTMENT NO. 1 — BLOCK NO. 1

	COVER TYPE	ACRES	*		COVER TYPE	ACRES
1	PIN 0-30	0.0	*	11	DEFOREST-B	0.0
2	PIN 31-50	342.2	*	12	DEFOREST-G	0.0
3	PIN 51-100	84.4	*	13	RECREATION	0.0
4	PIN 101-40	537.8	*	14	BARREN	8.9
5	PIN 141+	53.3	*	15	BRUSHLAND	0.0
6	SPR 0-30	0.0	*	16	RANGE-HERB	17.8
7	SPR 31-50	0.0	*	17	PRIVATE	231.1
8	SPR 51	0.0	*	18		-0.0
9	SPR 101-40	0.0	*	19		-0.0
10	SPR 141+	0.0	*	20		-0.0

TOTAL AREA 1275.5

PINE GROUP - 1017.7 SPRUCE GROUP - 0.0 DEFORESTED ACRES - 0.0

BOGUS NATIONAL FOREST — TYPE AREAS OF COMPARTMENT NO. 2 — BLOCK NO. 1

	COVER TYPE	ACRES	*		COVER TYPE	ACRES
1	PIN 0-30	0.0	*	11	DEFOREST-B	40.0
2	PIN 31-50	484.4	*	12	DEFOREST-G	0.0
3	PIN 51-100	71.1	*	13	RECREATION	0.0
4	PIN 101-40	528.3	*	14	BARREN	40.0
5	PIN 141+	8.9	*	15	BRUSHLAND	0.0
6	SPR 0-30	0.0	*	16	RANGE-HERB	0.0
7	SPR 31-50	0.0	*	17	PRIVATE	173.3
8	SPR 51	0.0	*	18		-0.0
9	SPR 101-40	0.0	*	19		-0.0
10	SPR 141+	0.0	*	20		-0.0

TOTAL AREA 1346.6

PINE GROUP - 1093.3 SPRUCE GROUP - 0.0 DEFORESTED ACRES - 40.0

BOGUS NATIONAL FOREST — TYPE AREAS OF COMPARTMENT NO. 3 — BLOCK NO. 1

	COVER TYPE	ACRES	*		COVER TYPE	ACRES
1	PIN 0-30	0.0	*	11	DEFOREST-B	111.1
2	PIN 31-50	102.2	*	12	DEFOREST-G	0.0
3	PIN 51-100	786.7	*	13	RECREATION	0.0
4	PIN 101-40	97.8	*	14	BARREN	0.0
5	PIN 141+	0.0	*	15	BRUSHLAND	0.0
6	SPR 0-30	0.0	*	16	RANGE-HERB	26.7
7	SPR 31-50	0.0	*	17	PRIVATE	124.4
8	SPR 51	0.0	*	18		-0.0
9	SPR 101-40	8.9	*	19		-0.0
10	SPR 141+	0.0	*	20		-0.0

TOTAL AREA 1257.8

PINE GROUP - 986.7 SPRUCE GROUP - 8.9 DEFORESTED ACRES - 111.1

APPENDIX 4

Basic Information Used

Tabulations and explanations that follow describe the relationships to be determined locally to adapt TEVAP to other species or conditions. Each relationship appears in TEVAP as one or more FORTRAN statements for each species or working group. Descriptions include explanations of the 21 program variables and related FORTRAN statements involved. Tabulations include only enough entries to explain the nature of the information needed, and do not indicate sample sizes or desirable ranges of data. Methods used to determine the relationships are found in standard mensuration texts and elsewhere (Myers 1966, Myers and Godsey 1968).

1. Stand density after thinning—

One set of relationships is based on the basal area to be left after intermediate cuts for various average stand diameters. These relationships control thinning intensity, after THIN(I) and DLEV(I) have been specified by the program user. Initial data needed take the following form:

Average stand d.b.h. after cutting (Inches)	Basal area per acre	Average stand d.b.h. after cutting (Inches)	Basal area per acre
	Sq. Ft.		Sq. Ft.
2.0	12.1	6.4	60.3
2.4	16.7	6.8	63.8
2.8	21.3	7.2	67.0
3.2	26.0	7.6	69.8
3.6	30.6	8.0	72.5
4.0	35.2	8.4	74.9
4.4	39.9	8.8	76.7
4.8	44.5	9.2	78.2
5.2	48.8	9.6	79.2
5.6	52.8	10.0+	80.0
6.0	56.6		

Values in this tabulation represent a few points on one of a family of curves (Myers 1966). Reserve basal area increases with average stand d.b.h. until 10.0 inches d.b.h. is reached. Thereafter, reserve basal area remains constant for any one growing stock level. In the tabulation, constant basal area is 80.0 square feet per acre, and the values represent growing stock level 80. Other levels are named similarly. Thus, if THIN(I) or DLEV(I) is 100, basal area at any d.b.h. below 10.0 inches is the basal area for level 80 multiplied by 100/80. If d.b.h. is greater than 10.0 inches, retained basal area is DLEV(I).

Several statements in subroutine CUTS are derived from basal area values for level 80. They are multiplied by terms including THIN(I) or DLEV(I), redefined as REST, to provide for a range of possible growing stock levels. Variables defined by the statements, and their use, are:

a. DBHP—to find a d.b.h. less than 10.0 inches when basal area is known. Three equations for DBHP are used to simplify representation of the nonlinear relationship between d.b.h. and basal area.

b. BREAK and BUST—to compute values of basal area that are the upper limits of applicability of the first two equations for DBHP.

c. SQFT—to find basal area when d.b.h. is known. Two equations represent the nonlinear relationship for d.b.h. less than 10.0 inches.

Two equations used to compute LEVL in subroutine GOT include the equations for SQFT. They give the equivalent growing stock level when average d.b.h. and basal area are known.

2. Tree heights in well-stocked stands—

Average height of dominant and codominant trees, where height growth is not reduced by high stand density, is computed from data of the form:

Main stand age (Years)	Site index class			
	40	50	60	70
20	8	10	13	16
40	17	22	28	34
60 ...	26	33	41	49
150	50	62	73	85

The relationships are expressed by statements for HTSO in subroutine GOAL. If data from site index curves are used, the crown classes described must be the same as those used to develop the site curves. The crown classes must be the same as those used in the equations for total cubic feet, described below.

3. Tree heights with variable stand density—

Future average heights of dominant and codominant trees, without restrictions on stand density, are computed as FHT(I) by subroutine GOT. Heights in 10 years are estimated from present average height, stand age, site index, and basal area. Data needed for regression analysis may be obtained from remeasurements of permanent plots or from borings and ring counts on temporary plots.

4. Future average stand d.b.h.—

Diameter in 10 years is estimated from present average d.b.h., site index, and present basal area. Future diameters are computed as FDM(I) by GOT and as DBHO by GOAL. Data needed to obtain the prediction equations by regression analysis are gathered on temporary or permanent plots.

5. Increase in average d.b.h. from thinning—

Effect of thinning from below on average stand d.b.h. is simulated by subroutine CUTS. One set of changes, replacement of equations for DBHE and PDBHE, is needed to adapt the routine to other species. DBHE and PDBHE represent the same item, estimated d.b.h. after thinning. DBHE is computed directly if the estimated percentage of trees to be retained is at least 50 percent. With fewer trees retained, PDBHE is computed and its antilogarithm becomes DBHE.

Prediction equations are derived, preferably by computer, in the sequence listed below. Additional discussion and a slightly different procedure appear elsewhere (Myers 1966, Myers and Godsey 1968).

a. Convert a series of stand tables of actual stands to 1000 trees each. Known values may be: (1) the average d.b.h. of each one-inch class and the number of trees in the class, or (2) a list of 1000 tree diameters.
b. Compute average d.b.h. of each stand (DBHO).
c. Create a set of 1000 randomly arranged diameters for each stand. Arrange individual diameters or class averages, whichever is available from step a.
d. Create groups of trees, based on percentages of trees to be retained (PRET), and tally the largest diameter in each group. For example, if 25 percent of the trees are to be retained, divide the 1,000 randomly arranged diameters into 250 groups of four trees each. Tally the largest diameter in each group of four trees.
e. Repeat step d for various percentages of retention and for each stand.
f. Compute the average d.b.h. (DBHE) that results from each percentage retention (PRET) in each stand.
g. Use regression analysis to obtain equations that predict DBHE from DBHO and PRET.
h. Compare predicted and actual values of DBHE, using data from actual stands, to insure that adequate predictions can be made.

6. Noncatastrophic mortality—

Reduction in number of trees through normal mortality may be important in unthinned stands, but minor and erratic in thinned stands. Stands with an average d.b.h. of 10.0 inches or larger are assumed to have no accountable mortality.

Future stand density is computed as FDN(I) by GOT and as DENO by GOAL. Definitions and values of both variables change during record processing. The first computation, the equation that varies by species, produces percentage mortality in 10 years, expressed as a decimal. The 10-year period equals the projection period of related equations that estimate future diameter and height. Later, FDN(I) or DENO is redefined as future number of trees and is computed from the original value of FDN(I) or DENO. This is a programing convenience to avoid additional memory locations.

7. Total cubic feet per acre—

Stand volumes in total cubic feet are computed with stand volume equations. As used in TEVAP,

cubic volume is determined from: (1) basal area per acre, average height of dominant and codominant trees, number of trees, and average stand d.b.h., or (2) from basal area and height alone. Both sets of variables have been significant in analyses of actual data.

Values of five variables are obtained from the same stand volume equations: TOT(I), FVL(I), and TVL(I) in GOT and TOTO and TOTT in GOAL.

8. **Conversion of total cubic feet to other units**—Volumes are first computed in total cubic feet per acre, as described above. They are then converted to other units by subroutine VOLS. The second column, below, shows some of the ratios used to obtain equations for FCTR. The third column shows ratios used to compute PROD.

Average stand d.b.h. (Inches)	Merchantable cubic feet ÷ total cubic feet	Board feet ÷ total cubic feet
5.1	0.355	--
6.0	.552	--
6.9	.725	--
8.3	.860	0.99
9.1	.901	1.55
10.3	.931	2.38
19.0	.962	5.33
23.4	.969	5.88

Volume or weight per acre of numerous stands are determined in units of interest and in total cubic feet. Then, the quantity of each unit per total cubic foot is determined. Selection of appropriate units includes choice of minimum merchantable top diameters and d.b.h.

APPENDIX 5

An Example of Record Maintenance

Program GROW, listed below, is an example of the assistance provided by computers in the maintenance of records. Its purpose is to update inventory records if thinning or other change has not required replacement with a new record. New inventory data and updated data can then be combined for input to TEVAP. The new management guide produced will be based on the most recent estimates of forest condition for all plots or subcompartments. The guide can be produced during the winter, between growing seasons, before it is needed to plan the next season's work.

Inputs to GROW are always original records, not the results of previous projections. A 9999 is punched instead of the year of record on inventory cards with updated information. Records with very large values for year will not be processed by the program. Accidental mixture of original and updated records will not be perpetuated for use by TEVAP. This feature requires that two sets of inventory records be prepared for each working circle:

1. A permanent file of original data that is revised only by replacement of records. This file is revised continuously as work and inventory reports are submitted, and is the input file for GROW.
2. A temporary file consisting of data updated by GROW and of duplicates of original data that are too new to need updating. This file contains the inventory records to be used by TEVAP.

Use of two files increases the complexity of the record system, but avoids the compounding of projection errors.

Linear projections are used in GROW because other forms of the relationships are unknown. For example, a 2-year increase in diameter is assumed to equal two-tenths of the increase projected by an equation developed for a 10-year period. Projection periods, the variable TIME in TEVAP, should, therefore, be kept short, especially for fast-growing species.

GROW produces three kinds of output, as follows:

1. An inventory card with updated data is punched for direct use or for transfer to magnetic tape. Alternatively, the logical unit assigned to the punch may be assigned to a tape drive. Card images of the temporary inventory file are then written directly onto tape.
2. A copy of the card or card image may be printed, if desired. A nonzero value of DUPL is read to obtain the printed record.
3. A record of the number of cards processed is written after all other operations have been executed. The total does not include any previously updated records accidentally mixed with original data.

```
      PROGRAM GROW
     1(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7=PUNCH,TAPE4=TAP
     2E5)
C
C  TO UPDATE INVENTORY IF NO CHANGES EXCEPT NORMAL GROWTH HAVE OCCURRED.
C
C  DEFINITIONS OF VARIABLES NOT ALREADY DEFINED IN PROGRAM TEVAP.
C       ADD = NUMBER OF YEARS TO PROJECT INVENTORY DATA.
C       ANO = YEAR AFTER LAST GROWING SEASON TO BE PROJECTED.
C       DUPL = INDEX TO PRINT (1) OR OMIT (BLANK OR 0) NEW DATA.
C       NBR = NUMBER OF INVENTORY CARDS PROCESSED.
C
      DIMENSION AGE(2),BAS(2),DATE(3),DBH(2),DEN(2),FAG(2),FDEN(2),FDM(2
     1),FHT(2),FORET(3),HT(2),JFAG(2),JFDEN(2),JFDM(2),JFHT(2)
      KNTR = 0
      NBR = 0
C
C  READ VALUES COMMON TO ALL CARDS.
C
      READ (5,1) (FORET(I),I=1,3)
    1 FORMAT (3A8)
      READ (5,1) (DATE(I),I=1,3)
      READ (5,2) RINT,DUPL,ANO,NBK
    2 FORMAT (3F4.0,I4)
C
C  INITIALIZE VARIABLES RECOMPUTED FOR EACH INVENTORY CARD.
C
   10 DO 11 I=1,2
      FAG(I) = 0.0
      FDEN(I) = 0.0
      FDM(I) = 0.0
      FHT(I) = 0.0
      JFAG(I) = 0
      JFDEN(I) = 0
      JFDM(I) = 0
   11 JFHT(I) = 0
      SBAS = 0.0
C
C  READ INVENTORY CARDS. LAST CARD IS BLANK TO STOP PROCESSING.
C  INVENTORY RECORDS ARE ORIGINAL DATA, NOT RESULTS OF PREVIOUS
C  PROJECTIONS. VARIABLE WHEN IS ACTUAL DATE, NOT DUMMY ADDED BY THIS
C  PROGRAM.
C
      READ (4,15) IBK,KOMP,ISUB,QTR1,QTR2,SECT,TOWN,RANG,SITE,STRY,NTYP,
     1WORK,DBH(1),HT(1),DEN(1),AGE(1),DBH(2),HT(2),DEN(2),AGE(2),ACRE,WH
     2EN
   15 FORMAT (I2,I4,I3,3A3,2A4,F4.0,F2.0,I3,F3.0,F4.1,F3.0,F5.0,F4.0,F4.
     11,F3.0,F5.0,F4.0,F5.1,F5.0)
C
C  DETERMINE IF GROWTH PROJECTION CAN BE MADE.
C
      IF(IBK .LE. 0 .OR. IBK .GT. NBK) GO TO 140


C
C  TEST DATE OF DATA SO PROJECTED DATA WILL NOT BE PROJECTED AGAIN.
C
      IF(WHEN .GE. 2000.0) GO TO 10
      NBR = NBR + 1
      ADD = ANO - WHEN
      IF(ADD .EQ. 0.0) GO TO 80
      IF(DEN(1) .EQ. 0.0 .OR. DBH(1) .EQ. 0.0) GO TO 80
C
C  COMPUTE FUTURE STAND VALUES.
C
      BAS(1) = 0.0054542 * DBH(1) * DBH(1) * DEN(1)
      BAS(2) = 0.0054542 * DBH(2) * DBH(2) * DEN(2)
      SBAS = BAS(1) + BAS(2)
      IF(NTYP .GT. 5) GO TO 30
      DO 20 I=1,2
      IF(DBH(I) .EQ. 0.0) GO TO 20
      IF(DEN(I) .EQ. 0.0) GO TO 20
      FAG(I) = AGE(I) + ADD
      IF(DBH(I) .GE. 10.0) GO TO 17
      FDEN(I) = 0.00247 + 0.00124 * DBH(I) + 0.00028 * DBH(I) * DBH(I) +
     10.0000521 * SBAS * SBAS - 0.0000905 * DBH(I) * SBAS
      IF(FDEN(I) .LT. 0.0) FDEN(I) = 0.0
      FDEN(I) = DEN(I) * (1.0 - FDEN(I))
      GO TO 18
   17 FDEN(I) = DEN(I)
   18 FDM(I) = 0.88511 * DBH(I) + 1.29735 * ALOG10(HT(I)) + 0.00119 * DB
     1H(I) * SITE + 62.37174 / SBAS - 1.56975
      FHT(I) = 15.43021 + 1.107 * HT(I) - 0.08637 * AGE(I)   304.1217. /
     1SITE - 0.02447 * SITE * SBAS * 0.01
   20 CONTINUE
      GO TO 50
   30 DO 40 I=1,2
      IF(DBH(I) .EQ. 0.0) GO TO 40
      IF(DEN(I) .EQ. 0.0) GO TO 40
      FAG(I) = AGE(I) + ADD
      IF(DBH(I) .GE. 10.0) GO TO 35
      FDEN(I) = 0.05285 - 0.01346 * DBH(I) + 0.00226 * DBH(I) * DBH(I) +
     10.0000066 * SBAS * SBAS - 0.0001931 * DBH(I) * SBAS
      IF(FDEN(I) .LT. 0.0) FDEN(I) = 0.0
      FDEN(I) = DEN(I) * (1.0 - FDEN(I))
      GO TO 36
   35 FDEN(I) = DEN(I)
   36 FDM(I) = 0.2631 + 0.95287 * DBH(I) + 0.0016 * DBH(I) * SITE + 16.4
     16662 / SBAS
      FHT(I) = 14.57349 + 1.101 * HT(I) - 0.09654 * AGE(I) - 333.37172 /
     1SITE - 0.04321 * SITE * SBAS * 0.01
   40 CONTINUE
C
C  CHANGE ORIGINAL VALUES TO THOSE EXPECTED IN ADD YEARS.
C
   50 TEM = ADD / RINT
      DO 51 I=1,2
      FDEN(I) = DEN(I) + (FDEN(I) - DEN(I)) * TEM
      FDM(I) = DBH(I) + (FDM(I) - DBH(I)) * TEM
      FHT(I) = HT(I) + (FHT(I) - HT(I)) * TEM
   51 CONTINUE
C
C  CHANGE TYPE CODES AS NEEDED.
C
      MNK = 0
      IF(NTYP .GT. 5) MNK = 5
      J = 1
      IF(STRY .GT. 0.0) J=2
      IF(FAG(J) .GT. 30.0) GO TO 55
      NTYP = 1 + MNK
      GO TO 70
   55 IF(FAG(J) .GT. 50.0) GO TO 56
      NTYP = 2 + MNK
      GO TO 70
   56 IF(FAG(J) .GT. 100.0) GO TO 57
      NTYP = 3 + MNK
      GO TO 70
   57 IF(FAG(J) .GT. 140.0) GO TO 58
      NTYP = 4 + MNK
      GO TO 70
   58 NTYP = 5 + MNK
C
C  CONVERT TO FIXED POINT FOR PUNCHING. RETAIN NECESSARY DECIMALS.
C
   70 DO 71 I=1,2
      JFDM(I) = FDM(I) * 10.0 + 0.5
      JFAG(I) = FAG(I) + 0.5
      JFDEN(I) = FDEN(I) + 0.5
      JFHT(I) = FHT(I) + 0.5
      FAG(I) = JFAG(I)
      FDEN(I) = JFDEN(I)
      FHT(I) = JFHT(I)
      FDM(I) = JFDM(I)
      FDM(I) = FDM(I) * 0.1
   71 CONTINUE
      GO TO 90
   80 DO 81 I=1,2
      FAG(I) = AGE(I)
      FDEN(I) = DEN(I)
      FDM(I) = DBH(I)
      FHT(I) = HT(I)
      JFAG(I) = AGE(I)
      JFDEN(I) = DEN(I)
      JFDM(I) = DBH(I) * 10.0 + 0.5
      JFHT(I) = HT(I)
   81 CONTINUE
   90 JSITE = SITE
      JSTRY = STRY
      JWORK = WORK
      JACRE = ACRE * 10.0 + 0.5
      JWHN = 9999


C
C  PUNCH REPLACEMENT FOR INVENTORY CARD, USING NEW DATA.
C
      WRITE (7,91) IBK,KOMP,ISUB,QTR1,QTR2,SECT,TOWN,RANG,JSITE,JSTRY,NT
     1YP,JWORK,JFDM(1),JFHT(1),JFDEN(1),JFAG(1),JFDM(2),JFHT(2),JFDEN(2)
     2,JFAG(2),JACRE,JWHN
   91 FORMAT (I2,I4,I3,3A3,2A4,I4,I2,2I3,I4,I3,I5,2I4,I3,I5,I4,2I5)
C
C  PRINT RECORD OF NEW INVENTORY DATA, IF DESIRED.
C
      IF(DUPL .EQ. 0.0) GO TO 10
      IF(KNTR .LE. 50) KNTR = 0
      IF(KNTR .NE. 0) GO TO 120
      WRITE (6,110)
  110 FORMAT (1H1,//,43X,39HRESULTS OF PROJECTION OF INVENTORY DATA)
      WRITE (6,111) (FORET(I),I=1,3),(DATE(K),K=1,3)
  111 FORMAT (1HO,8X,3A8,40X,18HDATA PROJECTED TO ,3A8)
      WRITE (6,112)
  112 FORMAT (1HO,50X,29H**********OVERSTORY**********,3X,29H**********UN
     1DERSTORY**********,12X,6HORIG./1H ,2X,5HBLOCK,2X,4HCOMP,2X,4HSUBC,
     222X,4HSITE,1X,5HSTORY,3X,4HTYPE,3X,4HWORK,4X,3HDBH,4X,2HHT,5X,5HTRE
     3ES,5X,3HAGE,5X,3HDBH,5X,2HHT,4X,5HTREES,5X,3HAGE,5X,4HAREA,4X,4HDA
     4TE)
      WRITE (6,113) IBK,KOMP,ISUB,SITE,STRY,NTYP,WORK,FDM(1),FHT(1),FDEN
     1(1),FAG(1),FDM(2),FHT(2),FDEN(2),FAG(2),ACRE,WHEN
  113 FORMAT (1HO,3X,I2,5X,I3,3X,I2,1X,F6.1,3X,F4.1,5X,I2,4X,F4.1,2X,F5.
     11,1X,F6.1,2X,F8.1,2X,F6.1,2X,F5.1,2X,F6.1,1X,F8.1,2X,F6.1,2X,F7.1,
     21X,F6.0)
      KNTR = KNTR + 1
      GO TO 10
  120 WRITE (6,121) IBK,KOMP,ISUB,SITE,STRY,NTYP,WORK,FDM(1),FHT(1),FDEN
     1(1),FAG(1),FDM(2),FHT(2),FDEN(2),FAG(2),ACRE,WHEN
  121 FORMAT (1H ,3X,I2,5X,I3,3X,I2,1X,F6.1,3X,F4.1,5X,I2,4X,F4.1,2X,F5.
     11,1X,F6.1,2X,F8.1,2X,F6.1,2X,F5.1,2X,F6.1,1X,F8.1,2X,F6.1,2X,F7.1,
     21X,F6.0)
      KNTR = KNTR + 1
      GO TO 10
C
C  RECORD THAT THE CHANGES WERE MADE.
C
  140 IF(DUPL .EQ. 0.0) GO TO 150
      WRITE (6,141) NBR
  141 FORMAT(1HO,//,5X,27HNUMBER OF CARDS REPUNCHED- ,I5)
      GO TO 160
  150 WRITE (6,151)
  151 FORMAT (1H1,////,43X,38HRECORD OF PROJECTION OF INVENTORY DATA)
      WRITE (6,152) (FORET(I),I=1,3)
  152 FORMAT (1HO,/,43X,16HSOURCE OF DATA- ,3A8)
      WRITE (6,153) (DATE(I),I=1,3)
  153 FORMAT (1HO,/,43X,18HDATA ADJUSTED TO- ,3A8)
      WRITE (6,154) NBR
  154 FORMAT (1HO,/,5X,27HNUMBER OF CARDS REPUNCHED- ,I5)
  160 CALL EXIT
      END
```

RESULTS OF PROJECTION OF INVENTORY DATA

[illegible] NATIONAL FOREST — DATA PROJECTED TO JAN 1, [illegible]

BLOCK	STMP	SUB	SITE	STORY	TYPE	WORK	OVERSTORY DBH	OVERSTORY HT	OVERSTORY TREES	OVERSTORY AGE	UNDERSTORY DBH	UNDERSTORY HT	UNDERSTORY TREES	UNDERSTORY AGE	AREA	YEAR
1	1	1	40.0	0.0	3	2.0	5.7	32.0	829.0	78.0	0.0	0.0	0.0	0.0	-0.0	1965.
1	1	2	60.0	0.0	4	0.0	12.2	57.0	125.0	121.0	0.0	0.0	0.0	0.0	-0.0	1968.
1	1	7	40.0	0.0	5	4.0	9.2	49.0	318.0	149.0	0.0	0.0	0.0	0.0	-0.0	1967.
1	[illegible]	5	50.0	1.0	3	9.0	12.4	58.0	2.0	124.0	5.0	42.0	617.0	74.0	8.7	1966.
1	2	9	70.0	0.0	4	4.0	14.4	83.0	70.0	134.0	6.5	60.0	126.0	74.0	173.3	1966.
1	2	13	60.0	0.0	11	1.0	0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	1965.
1	3	1	50.0	1.0	3	6.0	12.1	48.0	2.0	122.0	5.2	32.0	[illegible]	73.0	364.4	1967.
1	3	3	60.0	0.0	4	0.0	13.2	66.0	238.0	122.0	0.0	0.0	0.0	0.0	-0.0	1965.
1	3	6	70.0	0.0	11	1.0	0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	1967.
1	3	10	60.0	0.0	3	0.0	10.7	59.0	204.0	94.0	[illegible]	0.0	0.0	0.0	320.0	1968.
1	5	1	60.0	0.0	4	0.0	10.1	60.0	246.0	104.0	0.0	0.0	0.0	0.0	-0.0	1966.
1	7	10	50.0	0.0	2	2.0	5.1	29.0	658.0	50.0	0.0	0.0	0.0	0.0	-0.0	1968.
1	9	14	50.0	0.0	3	2.0	6.1	31.0	419.0	52.0	0.0	0.0	0.0	0.0	-0.0	1967.
[illegible]	88	1	50.0	0.0	3	0.0	3.8	19.0	599.0	34.0	0.0	0.0	0.0	0.0	-0.0	1966.
[illegible]	88	4	60.0	0.0	3	2.0	6.2	49.0	1217.0	73.0	0.0	0.0	0.0	0.0	-0.0	1965.
2	88	13	60.0	0.0	4	0.0	10.3	66.0	238.0	129.0	0.0	0.0	0.0	0.0	-0.0	1966.
2	89	4	60.0	0.0	1	0.0	0.0	3.0	580.0	10.0	-0.0	-0.0	-0.0	-0.0	-0.0	1967.
2	100	1	60.0	0.0	9	2.0	11.5	61.0	227.0	105.0	0.0	0.0	0.0	0.0	-0.0	1965.
2	100	2	50.0	0.0	4	0.0	9.3	55.0	204.0	119.0	0.0	0.0	0.0	0.0	-0.0	1967.
2	100	4	50.0	0.0	1	0.0	3.0	11.0	1994.0	21.0	0.0	0.0	0.0	0.0	17.8	1969.
2	100	5	60.0	0.0	3	4.0	11.8	56.0	198.0	85.0	5.2	48.0	302.0	65.0	-0.0	1965.
2	100	7	60.0	0.0	4	0.0	10.4	69.0	238.0	125.0	0.0	0.0	0.0	0.0	-0.0	1965.
2	100	9	60.0	0.0	4	6.0	12.4	69.0	3.0	125.0	6.9	51.0	503.0	75.0	-0.0	1965.
2	100	16	50.0	0.0	5	4.0	13.8	60.0	101.0	144.0	0.0	0.0	0.0	0.0	-0.0	1965.
2	101	2	50.0	1.0	3	0.0	12.4	56.0	1.0	125.0	7.9	46.0	290.0	85.0	-0.0	1965.
2	102	2	50.0	1.0	2	6.0	14.2	55.0	10.0	121.0	2.2	22.0	2969.0	37.0	8.9	1968.
2	102	9	60.0	0.0	4	5.0	14.1	64.0	44.0	131.0	7.1	40.0	348.0	61.0	53.3	1969.
2	102	15	70.0	0.0	8	2.0	7.5	48.0	476.0	59.0	0.0	0.0	0.0	0.0	-0.0	1965.
3	202	1	40.0	0.0	5	4.0	11.2	50.0	78.0	153.0	0.0	0.0	0.0	0.0	66.7	1968.
3	208	2	60.0	0.0	5	5.0	12.1	73.0	76.0	151.0	4.1	48.0	684.0	71.0	-0.0	1969.
3	207	10	70.0	0.0	5	4.0	17.0	87.0	36.0	153.0	0.0	0.0	0.0	0.0	-0.0	1965.
3	203	11	60.0	0.0	3	2.0	5.4	52.0	998.0	81.0	0.0	0.0	0.0	0.0	-0.0	1965.
3	203	9	60.0	0.0	4	0.0	7.3	64.0	372.0	108.0	0.0	0.0	0.0	0.0	-0.0	1967.
3	203	7	60.0	0.0	4	2.0	9.5	62.0	398.0	115.0	0.0	0.0	0.0	0.0	-0.0	1965.
3	203	5	50.0	0.0	5	6.0	14.0	60.0	35.0	161.0	3.1	29.0	2272.0	51.0	40.0	1969.
3	203	3	70.0	0.0	3	2.0	8.3	64.0	448.0	85.0	0.0	0.0	0.0	0.0	-0.0	1965.
3	203	2	60.0	0.0	4	2.0	8.4	64.0	395.0	110.0	0.0	0.0	0.0	0.0	-0.0	1965.
3	203	1	50.0	0.0	5	4.0	11.6	56.0	124.0	144.0	0.0	0.0	0.0	0.0	31.1	1968.
3	202	4	60.0	0.0	3	2.0	2.8	39.0	4459.0	55.0	0.0	0.0	0.0	0.0	-0.0	1965.
3	202	8	50.0	0.0	4	0.0	10.0	56.0	68.0	115.0	1.9	26.0	1087.0	45.0	-0.0	1965.
3	202	7	60.0	0.0	3	2.0	5.3	30.0	858.0	52.0	0.0	0.0	0.0	0.0	13.3	1968.

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1970. Computer assisted timber inventory analysis and management planning. USDA Forest Service Research Paper RM-63, 53 p. Rocky Mountain Forest and RAnge Experiment Sation, Fort Collins, Colorado 80521.

Presents computer programs, written in Fortran IV, for analysis of inventory data, computation of actual and optimum growing stocks and allowable cuts, and computation of other values needed for forest management planning. Computed volumes and areas are summarized in a timber management guide that replaces a conventional management plan. Effects of cultural operations and other changes are accounted for in computation of both actual and optimum conditions.

Key Words: Allowable cut, forest management, stand yield tables, timber management.

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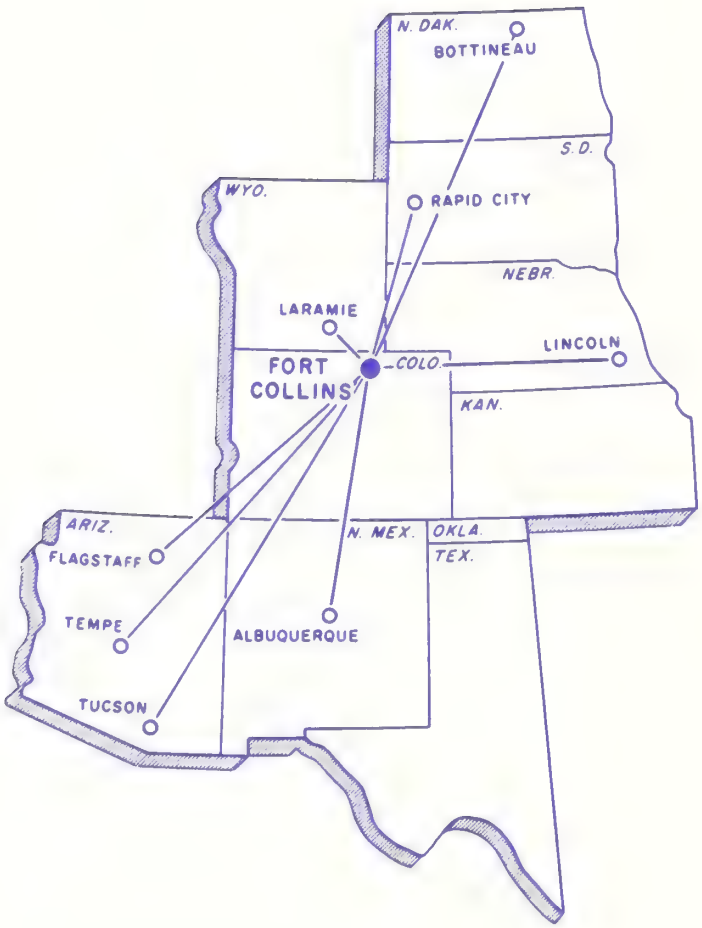
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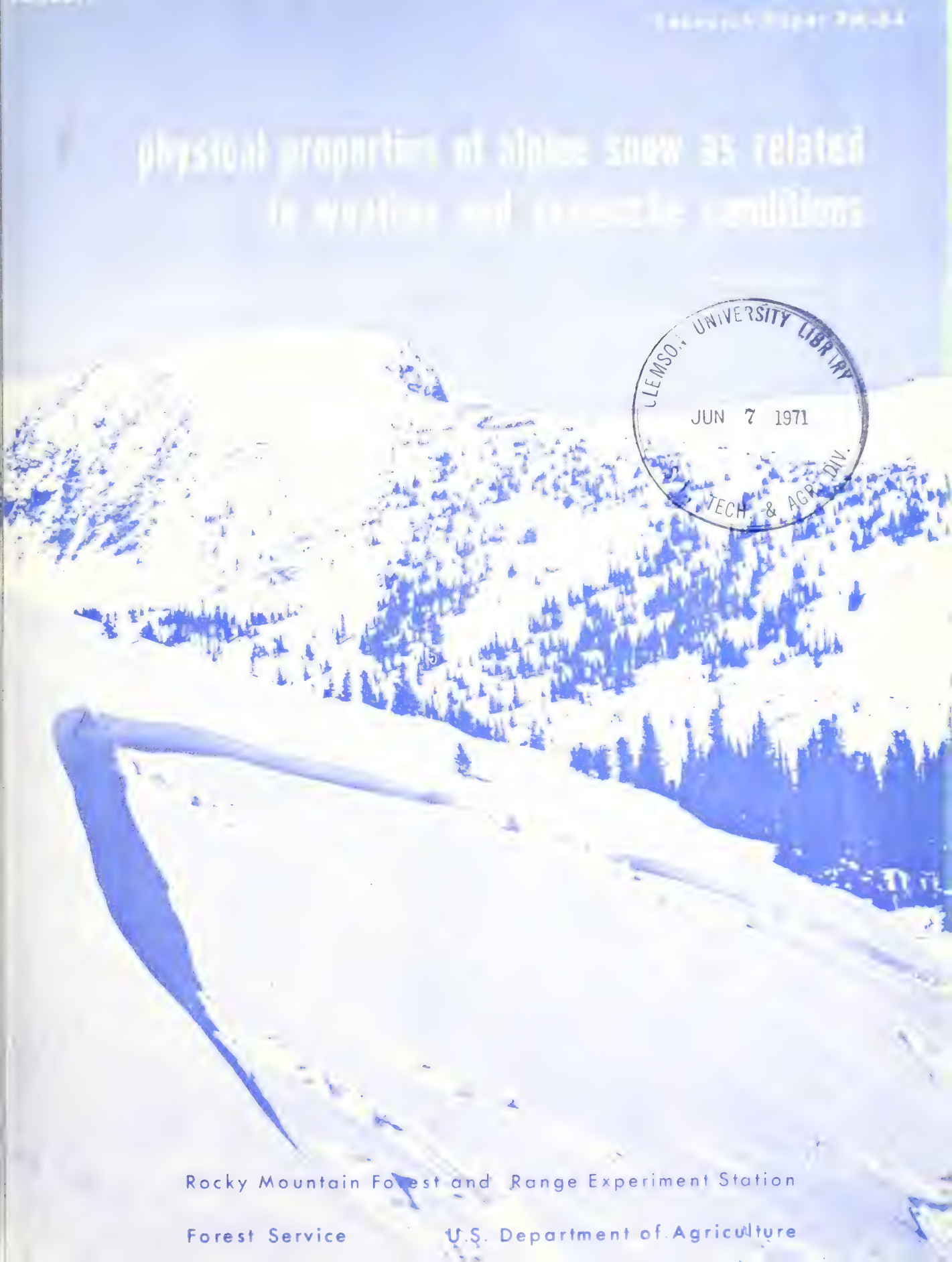

Rocky Mountain Forest and Range Experiment Station

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ABSTRACT

Data were taken in avalanche starting zones at an elevation of 11,700 feet in Front Range of Colorado within 14 days of deposition. Densities varied from 40 to 450 kg m^{-3}. A statistical criterion was used to identify snow with unusually high density for its age (initial hard slab) and unusually low (persistent soft snow). Initial hard slab, found in 15 percent of the pits, was correlated with moderate to high windspeeds, low temperatures, and presence of wind-transported snow. No good way was found to distinguish initial hard slab from dense older snow. Tensile strength from a spin test varied from 1.0 to 1712 grams force cm^{-2}. Strength increased with density but varied greatly for given density. Younger snows tended to be weaker than older snows of same density. Strength was also measured with shear box and shear vane. Ram resistance was higher for alpine snow than for snow of same density in the trees. Air permeability was an order of magnitude less than expected and varied with the low flow rate used. The ratio virtual porosity/porosity, which averaged 1.062, was of little value for identifying wind slab. Strength of snow of given density was greater for a certain permeability (texture) than for any other.

KEY WORDS: Avalanches, snow, weather, permeability, snow density.

ABOUT THE COVER:

This hard-slab avalanche was released in the study area 19 Feb 1966 by an explosive charge. The fracture face in the shadowed area is 7 feet tall. The avalanche slid over an old snow surface in the top of the track, but went to ground farther down the 600-foot-long track. Angular blocks in the debris are typical of hard-slab avalanches. The fact that many of the blocks could be fitted back together suggests brittle failure of the snow. The ripples and pockmarks on the srow surface outside the slide area are the result of wind action.

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Physical Properties of Alpine Snow as Related to Weather and Avalanche Conditions

by

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Physical Properties of Alpine Snow as Related to Weather and Avalanche Conditions

M. Martinelli, Jr.

Background

The avalanche classification proposed by de Quervain (1966) and used in many countries differentiates between hard slab and soft slab avalanches.[2/] The field designation for hard or soft slab is usually based on the size and shape of the debris left by the avalanche. Distinct angular blocks of snow in the debris indicate hard slab, while amorphous mounds or sheets of debris distinguish the soft slab—provided, of course, the telltale fracture line of the slab avalanche is present in the starting zone.

It is generally agreed that wind action, either during snowfall or during the transport and redeposition of old snow, toughens the snow and often leads to slab formation. Seligman (1936) says soft slab forms when the amount of precipitation or drift snow is too great for the wind to pack solidly. Hard slab, according to him, is the result of the amount of icing (cementing or bonding), which he attributes to the duration and intensity of winds. Others (U.S. Forest Service 1961) have said that, although wind is one of the predominant natural factors in slab formation, wind alone is neither necessary nor sufficient to cause slab formation in snow-covered areas.

LaChapelle (1966) states that hard slab is the principal type of avalanche in the Rocky Mountain region of the United States, and implies it is the result of cold temperatures and strong winds. Judson (1967) agrees that hard slab is often formed in Colorado during periods of light snowfall and cold temperatures. He points out, however, that soft-slab avalanches outnumber hard-slab avalanches three to one in Central Colorado—a proportion common to many areas.

Although there seems to be considerable doubt about the frequency, distribution, and cause of hard slab formation, practical experience has shown that the operational procedures necessary to maintain safety on winter sports areas and along mountain highways are different for hard-slab and soft-slab conditions. For example, when hard slab is present:

1. Slope stabilization by protective skiing is difficult and very uncertain.
2. Explosive control is also difficult because hard slab is often highly localized. For this reason, an avalanche released on one slide path seldom propagates to other paths, as often happens with more widespread soft slab. This means each danger spot must be controlled directly.
3. Heavier than usual explosive charges are needed because of the greater strength of hard slab.
4. Different target areas become important.

It is of more than academic interest, therefore, to be able to determine the type of slab present before an avalanche runs, and to know more about the weather conditions causing different types of slab.

Objectives

This study was undertaken (1) to determine the physical and mechanical properties of newly deposited snow, and (2) to correlate these properties with the weather factors during deposition, with special emphasis on the factors leading to hard slab. More specifically, we wanted to see (1) if the ratio of virtual porosity to actual porosity (Bader 1954) could be used to identify wind slab; (2) what wind, temperature, and precipitation conditions were important for the two types of slab; and (3) what mechanical or physical properties could be used to distinguish hard from soft slab without having to wait for an avalanche to run.

2/*The term slab avalanche is the English translation of the German term Schneebrettlawine and refers to avalanches of snow with an appreciable degree of internal bonding (Mellor 1968).*

Study Site and Data Taken

Data were taken in the starting zones of several small avalanches at an elevation of 11,700 feet, near Berthoud Pass in the Front Range of Central Colorado (fig. 1).

Slopes were steep (average gradient about 35°) and rocky, with a sparse cover of grasses, sedges, and forbs. Exposures varied from north through east. Scattered islands of short, wind-trimmed spruce and fir trees (Krummholz) were present around the edges of several of the avalanche paths. The upper limit of erect tree growth was 250 to 300 feet below the study site. Within 5 miles of the site there are 55 avalanche paths that cross interstate highways, or threaten mining operations, homes, or public ski areas. There are 74 such paths within 10 miles, and 112 within 15 miles.

The following weather data were available either from the routine climatic observations being taken at the Pass, or as a part of this study:

Windspeed and direction were taken 6 feet above the snow, 75 to 100 feet uphill from the study area; air temperature and precipitation were recorded and snow depths measured daily in a small opening in the timber 400 feet below and 1/4 mile northeast of the study site; new snow depths were measured at intervals of several days on stakes located in the study area.

At selected spots, specific snowcover data were taken following two storms in the winter 1964-65, one in 1965-66, eight in 1966-67, and seven in 1967-68. One additional set of data was gathered at the Urad Mine 4 miles southwest of the study

Figure 1.--Study site in the Front Range of Colorado. Berthoud Pass, where U. S. Highway 40 crosses the Continental Divide, is in the lower left foreground. The avalanche path called the Roll is the smooth, curving slope marked A. Q-12 Park where climatic data were taken is the small opening in the trees marked B.

site in March 1965. For the last two winters, data were gathered for most of the significant storms. These data included:

> Ram resistance, snow stratigraphy, snow temperature, grain size, grain type, snow density, air permeability, and three independent indexes of strength.

Ram resistance was usually measured for the entire depth of the snow cover. Other items were measured for each significant layer within the new snow. When avalanches had just run, most of the above data were taken in the undisturbed snow just above the fracture line. The centrifugal test for tensile strength was started in December 1966.

General Field Procedure

When a storm was imminent, several snowboards were placed in the avalanche loading zone to aid in dating the new snow. After the storm, resistance to penetration was measured for the entire snow depth near one of the snowboards with a rammsonde (Bader 1954, Niedringhaus 1965). This also established total snow depth, height of snowboard above ground, and a convenient height reference for all subsequent data.

A pit, dug down to the snowboard, exposed a cross section of the new snow. Snow layers were delineated by visual inspection or, in most cases, by inserting a piece of stiff plastic into the pit wall and moving it slowly upward to detect changes in hardness. Snow grain size and type were estimated with the aid of a millimeter grid and hand lens according to the International Classification (International Association of Hydrology 1954). Snow temperature was measured at 10-cm intervals with a thermistor probe and a bridge circuit (Swanson 1962).

Samples were taken in each significant snow layer with the standard SIPRE (USA CRREL) 500 cm^3 samplers (189 mm long and 58 mm in diameter). Some samples were taken parallel to the layering for tensile strength tests; others were taken perpendicular to the layers for air permeability. All samples were weighed to determine density.

Small benches were prepared in the pit wall near the center of each snow layer, and shear strength was measured in place by two methods—the torque vane and the shear frame.

Snow crystals were photographed, and air permeability and tensile strength tests were carried out on field samples in an unheated hut near the study site. Temperature in the hut was usually well below freezing.

Physical and Mechanical Properties

Physical and mechanical properties are summarized in the Appendix.[3/] For the most part, the snow was less than 2 weeks old. This new snow averaged 5 days of age when sampled; in a few cases, ages were not known or were in excess of 2 weeks. Where such data are used in this report, they are clearly marked.

Density

This well known and relatively easy-to-measure feature is the most definitive single property of snow. Density of younger samples varied from 40 to 450 kg m^{-3}; it went to 500 kg m^{-3} in a few of the older samples of unknown age.

Density was computed for both perpendicular and horizontal samples. The horizontal samples were usually taken very near the midpoint of the perpendicular samples. A "t" test applied to 67 pairs of density samples showed no significant difference between horizontal and vertical samples:

	Horizontal	Vertical
Average density (kg m^{-3})	254	257
Standard deviation	+0.088	+0.083
Coefficient of variation (percent)	34.8	32.1

Density sampling gave no difficulties except on a few occasions when very tough, older snow was encountered near the bottom of deep pits. In such cases, it often took two men to push the sample tube into the snow, and once or twice the cutting edge of the steel tube was bent by ice layers.

A scatter diagram of density (ρ) versus age (t) showed a general increase in density with age, with the greatest increase in the first 2 to 3 days

[3/] *Profiles of all pits were also prepared, but are not included in this report. Copies of the working version of the profiles can be obtained by request.*

(fig. 2). It also showed four points (marked +) with unusually high densities for their age, and three others (marked Δ) with densities only about half those expected. This confirmed field observations that some of the young snow layers were unusually hard and dense for their age, while a few of the older layers had remained remarkably soft.

The regression equation is

$$\rho = 161 + 0.139 \log (t)$$

$$r = 0.61$$

The 95 percent continuous confidence interval for this regression based on five density samples for each age, is delineated by dashed lines in figure 2. Samples above the upper confidence limit are called initial hard slab; those below the lower limit are called persistent soft snow. The remainder are called typical aged snow.

There are several things that should be pointed out about the designations just described. First, the statistical approach offers a convenient and somewhat objective way of making the distinctions while still recognizing the continuous nature of the density-age relation. Second, the decision to use the density-age relation rather than strength—age or ram resistance—age was arbitrary, as was the choice of the five-sample continuous confidence interval.

The use of the term **initial hard slab** was an attempt to distinguish snow that develops high density and strength in the first few days from that which has had several weeks or a month to toughen. The current definition of hard slab is based solely on the degree of cohesion as reflected in the shape of blocks in the avalanche debris, and does not distinguish between 1.5- to 2-day-old initial hard slab and aged snow 2 to 4 weeks old. Typical aged snow and persistent soft snow would be called soft slab by the average field man.

Table 1 was prepared to see how well the concept of **initial hard slab** based on density-age relations compared to the type of avalanches actually observed. Most of the avalanches within a 5-mile radius of the study area that ran on the 3 days

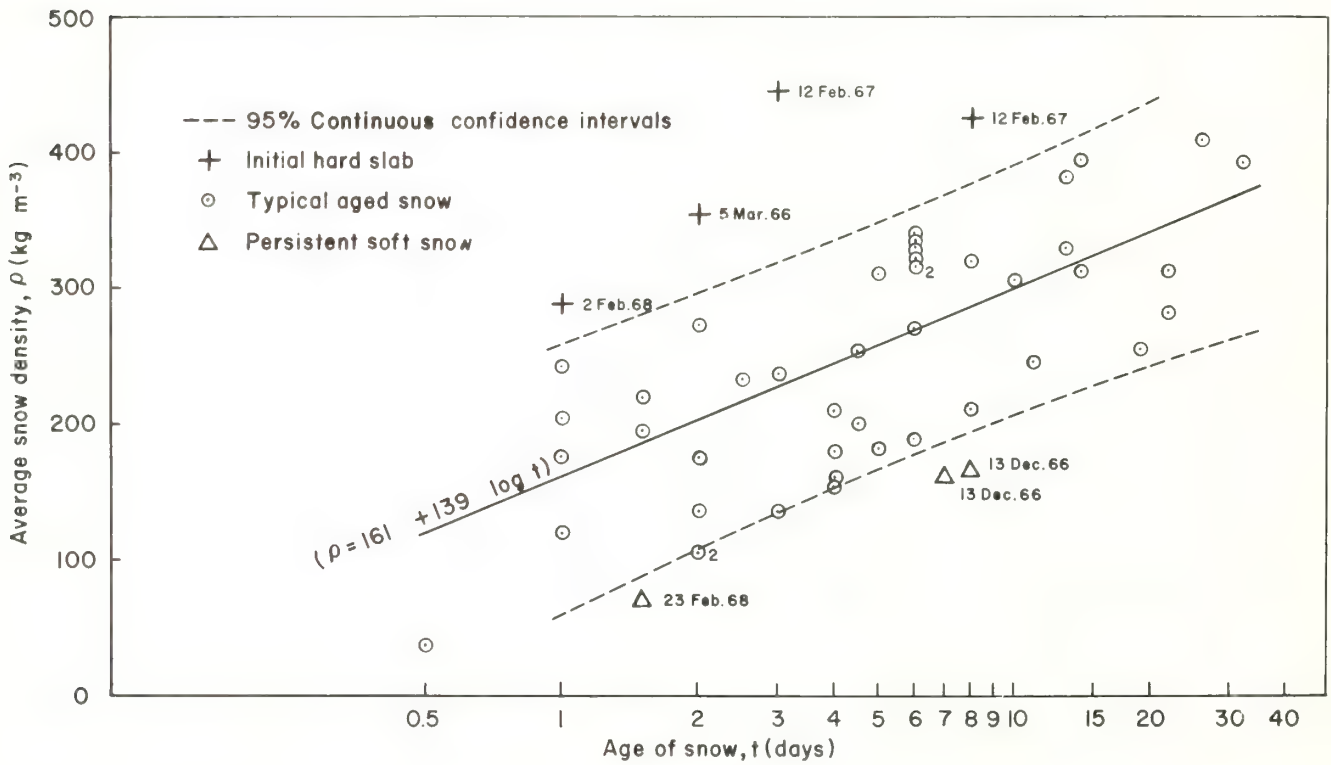


Figure 2.--Density (ρ) as a function of age (t). Points are the average of two to four density samples. Numbers indicate places where one symbol represents two points. Continuous confidence intervals (95 percent) are for the means of five samples for each age.

when initial hard slab was observed in the study pits (March 5, 1966, February 12, 1967, and February 2, 1968) were hard slab avalanches. On all other study days, except February 3-4, 1965, soft slab avalanches predominated. There is no way to be sure if the hard slab avalanches of February 3-4, 1965 were from initial hard slab or from older snow, because the snow at the study site in the Lift Gully could not be aged accurately. It was impossible to determine in the field if the hard slab avalanche that ran down the Lift Gully on February 2, 1965 started above or below the fracture line of the soft slab avalanche that had run in the same area on January 28, 1965. If the February avalanche started downhill of the January fracture line, the February snow would have been about 3 days old and would have been designated initial hard slab. Since we couldn't be sure of this, however, it seemed more likely the snow involved in the February avalanche was at least 6 days old, and should be called typical aged snow.

A more general, season-long comparison of the frequency of initial hard slab and the occurrence of hard slab avalanches can be made from table 2. For the 3-year study period, 1965-68, initial hard slab was found in 15 percent of the pits. Yet on a dozen or more avalanche paths immediately adjacent to the study site, about one-fourth of the natural and between 30 and 40 percent of the artificially released avalanches were of the hard slab variety. For the 18-year period, 1950-68, the proportion of hard slab avalanches in the grand total was 30 percent, or about double the frequency of initial hard slab conditions observed during the study. This is probably due to the high proportion of artificially released avalanches which, because of the relatively severe trigger, often involve layers of older snow.

Table 1.--Type of snow found in snow pits and type of avalanches observed within 5 miles of the study site on or near date pit was dug

Pit date	Type of snow in pit	Type of avalanches			Avalanche date
		Soft slab	Hard slab	Loose	
		Number			
1965					
28-29 Jan	Typical aged	4	0	0	28 Jan
		6	1	1	29 Jan
3-4 Feb	Typical aged	1	4	0	2 Feb
		0	2	0	3 Feb
15-16 Mar	Typical aged	1	0	0	13 Mar
		4	1	0	14 Mar
		3	0	0	15 Mar
1966					
5 Mar	Initial hard slab	0	1	0	4 Mar
		0	2	0	5 Mar
7 Dec	Persistent soft	2	0	0	7 Dec
		5	0	0	9 Dec
13 Dec	Persistent soft	0	0	0	
1967					
3-4 Jan	Typical aged	2	0	0	3 Jan
		4	0	0	4 Jan
6 Jan	Typical aged	1	0	0	6 Jan
		1	0	0	7 Jan
15 Jan	Typical aged	3	0	0	14 Jan
		5	0	0	15 Jan
		2	0	0	16 Jan
31 Jan	Typical aged	0	0	0	
1 Feb	Typical aged	0	0	3	1 Feb
12 Feb	Initial hard slab	2	3	0	11 Feb
		1	0	0	13 Feb
7-8 Dec	Typical aged	4	1	0	7 Dec
		3	0	0	9 Dec
21 Dec	Typical aged	1	0	0	21 Dec
		3	0	0	22 Dec
1968					
17-19 Jan	Typical aged	2	0	0	13 Jan
2 Feb	Initial hard slab	1	0	0	1 Feb
		0	1	0	3 Feb
20 Feb	Typical aged	4	0	0	20 Feb
23 Feb	Persistent soft	1	0	0	22 Feb
		5	0	0	23 Feb
		6	0	0	24 Feb
29-30 Apr	Typical aged	0	0	3	30 Apr
Total		80	16	7	

Table 2.--Slab avalanches in or near the Berthoud Pass study area

Date and type of release	Type of avalanche				Total avalanches	
	Soft slab		Hard slab			
	No.	Pct.	No.	Pct.	No.	Pct.
1950-68:						
Natural	66	77	20	23	86	19
Artificial	255	68	120	32	375	81
Total or average	321	70	140	30	461	100
1965-68:						
Natural	30	71	12	29	42	30
Artificial	59	60	40	40	99	70
Total or average	89	63	52	37	141	100

If there is any justification in calling the Central Rocky Mountains "the home of the hard slab avalanche," it is not just because of initial hard slab, but also because, in this area of low to moderate snowfall, vigorous explosive control and natural triggers often released older snow layers that have had time to harden and toughen in place.

Grain Size and Type

The snow in the various layers was classified in the field as new snow (type a), settled powder or felted snow (type b), fine-grained old snow (type d), or a mixture of the last two types (fig. 3) (International Association of Hydrology 1954). Experienced

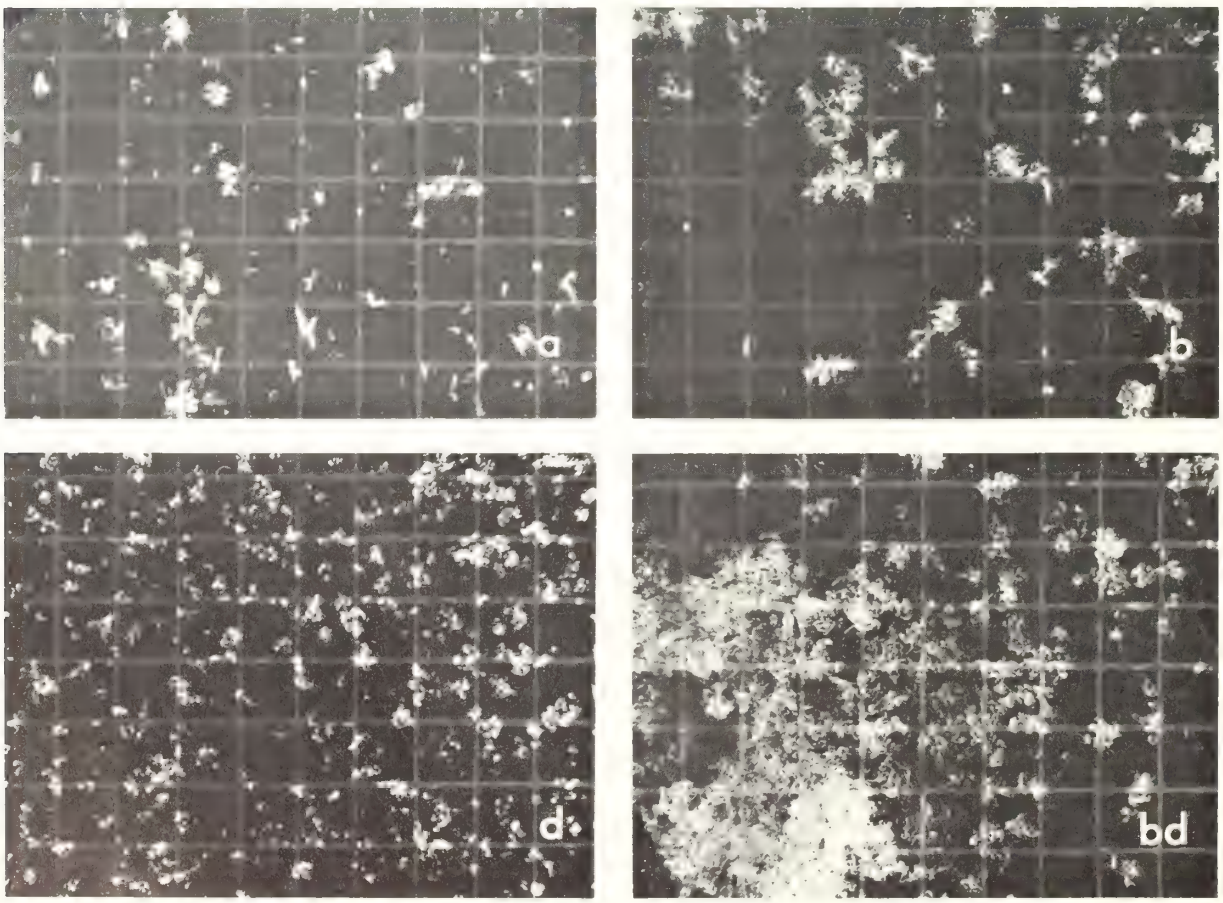
Figure 3.--Snow grain type and size illustrated by pictures from crystal camera (see fig. 5). Grid in background is 2 mm.

Grain type: a
Size: 1 mm
Age: falling snow
Depth: at surface
Density: unknown
Ram resistance: unknown
Tensile strength: unknown
Date: 20 Feb 68

Grain type: b
Size: 1 mm
Age: 1 - 1.5 days
Depth: 28 cm
Density: 68 kg m^{-3}
Ram resistance: 1 kg
Tensile strength: 4.78 gf cm^{-2}
Date: 23 Feb 68

Grain type: d
Size: 0.5 mm
Age: 13 days
Depth: 83 cm
Density: 326 kg m^{-3}
Ram resistance: 48 kg
Tensile strength: 860 gf cm^{-2}
Date: 31 Jan 67

Grain type: bd
Size: 1.5 mm
Age: 4 days
Depth: 15 cm
Density: 222 kg m^{-3}
Ram resistance: 1 kg
Tensile strength: 118 gf cm^{-2}
Date: 30 Apr 68



observers were consistent in their identification of snow type, although we suspected that, rather than relying completely on the physical appearance of the grains, they were subconsciously integrating into their determinations such things as past weather, depth within the pack, relative age, hardness, and density.

As expected, fine-grained old snow (type d) had greater strength, density, and hardness than felted snow (type b). The bd mixture was intermediate in these features. Initial hard slab was fine grained and had high strength and hardness at an early age (fig. 4).

Most of the snow grains were between 0.4 and 0.7 mm in diameter. The new snow tended to be larger grained, especially when it fell with little or no wind. The nature of the study did not require sampling the coarse-grained lower layers, where more active metamorphism had been in progress longer. Grain size in these lower layers, however, is known to range from 1 to 3 mm with a few grains in favorable situations as large as 5 to 7 mm.

Snow grains from the tensile strength samples were photographed in the cold room with a 35 mm camera equipped with extension tubes and an electronic flash (fig. 5). This procedure was fast and gave a life-size image on the negative which could be enlarged many times by standard darkroom techniques for detailed subsequent examination. Examination of many such pictures indicated that a better classification scheme was needed for snow on the ground. Since the completion of this study, such a classification based on the physical processes causing the change and on modern crystallographic concepts has been published by Sommerfeld and LaChapelle (1970).

Figure 4.--Snow grains from initial hard slab. Density 448 kgm^{-3}; age 3 days; tensile strength 635 gf cm^{-2}; ram resistance 100 kg. Background grid 2 mm.

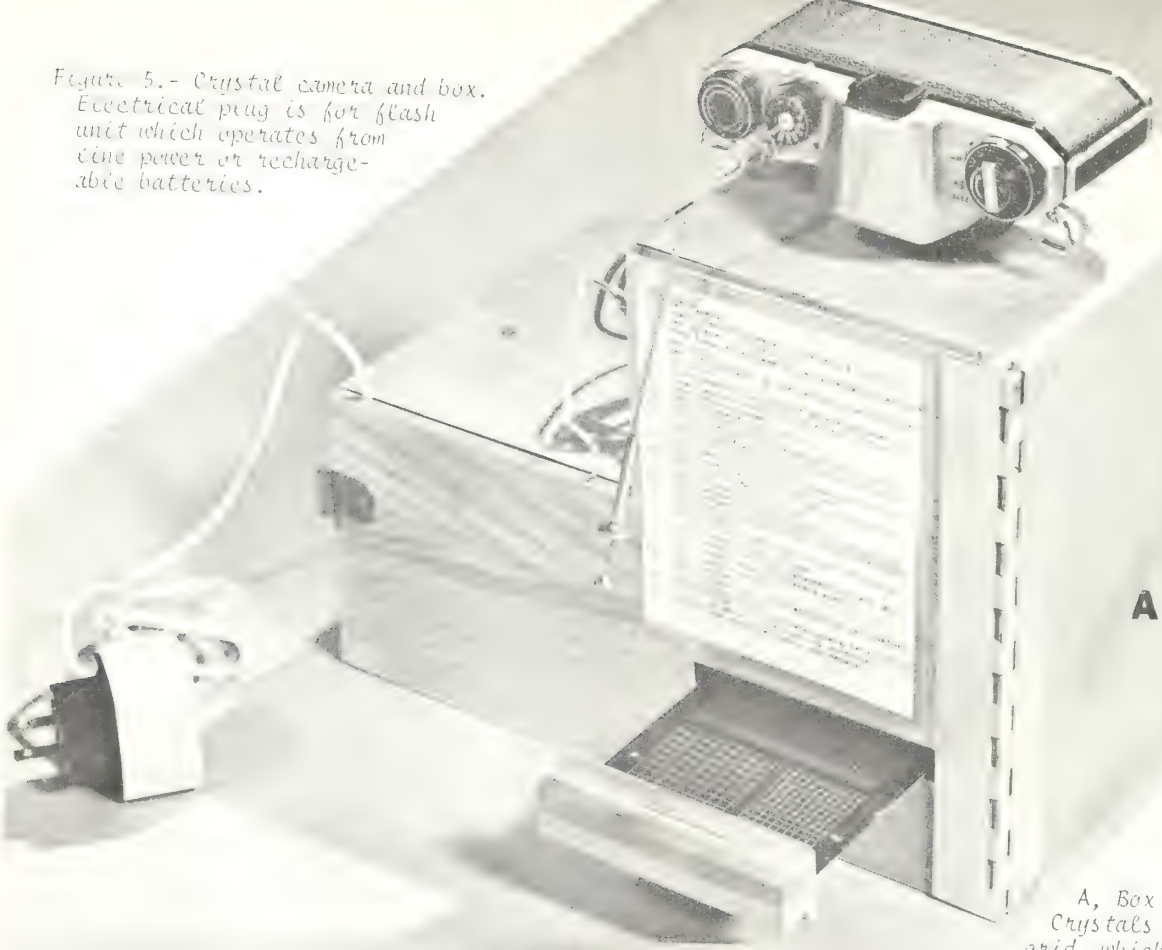
Strength

Fresh snow is usually so soft and poorly bonded, and so subject to changes with temperatures and time, that classic strength tests such as unconfined compression and simple tensile are difficult to perform. In their place, a series of field and laboratory tests have been devised that at least give indexes of strength (Bader et al. 1951, de Quervain 1951, Perla 1969).

The centrifugal or spin tester illustrated in figure 6 was used to measure tensile strength. A cylindrical sample of snow was taken parallel to the layering in a 500 cm^3 sample tube. The field sample was then taken to an unheated hut and transferred to a similar tube mounted on top of the tester by placing the two tubes end to end and pushing the snow from one to the other with a wooden ram. Care was needed in transferring samples of very porous snow, but samples with densities as low as 40 kg m^{-3} were successfully tested. A yoke that fits into grooves in the tube restrained the sample in the middle and reduced its cross-sectional area. The sample was then spun horizontally, by means of a variable-speed electric motor. Speed was increased two to three revolutions per second, or about 50 to 75 gf cm^{-2} sec^{-1} for a sample of 250 kg m^{-3} density.[4/]

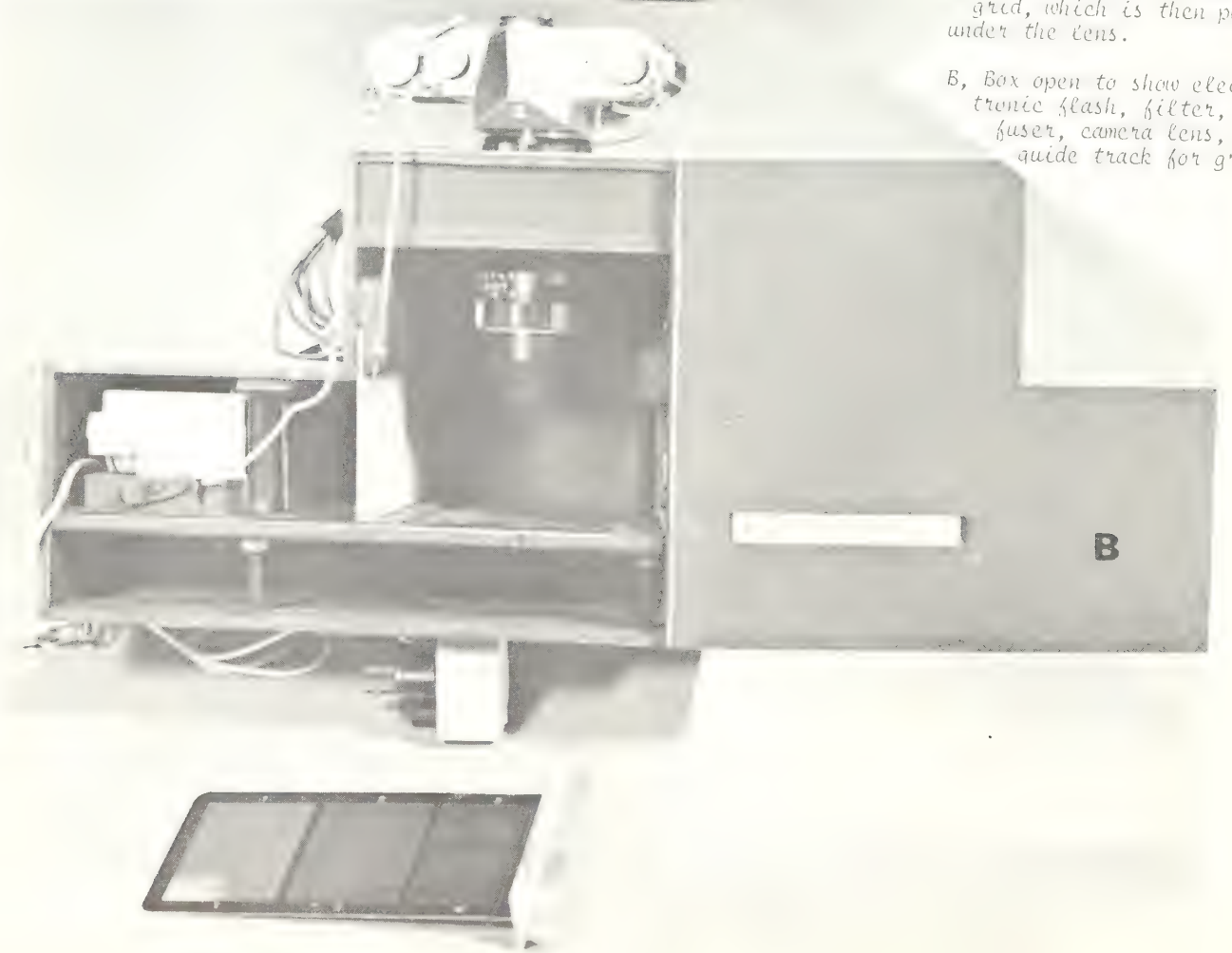
[4]*Grams force is abbreviated as gf in this paper. 1 gf = .0098 Newton*

Figure 5.- Crystal camera and box. Electrical plug is for flash unit which operates from line power or rechargeable batteries.



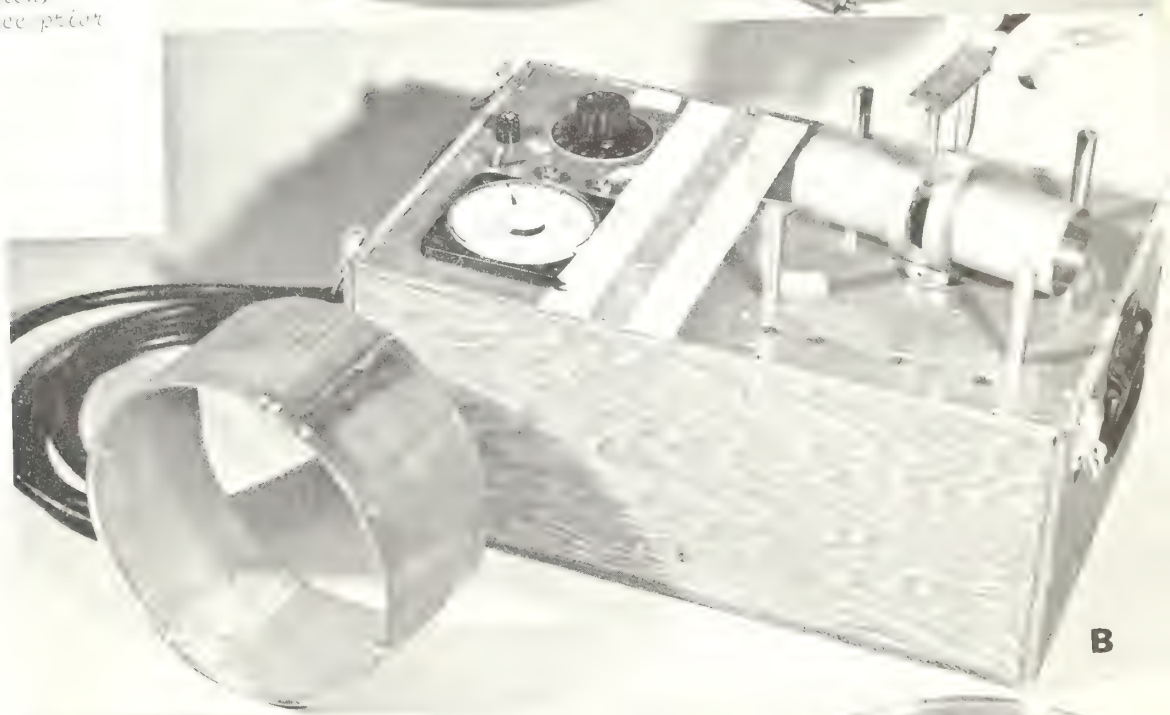
A

A, Box closed for use. Crystals are placed on grid, which is then pushed under the lens.



B

B, Box open to show electronic flash, filter, diffuser, camera lens, and guide track for grid.



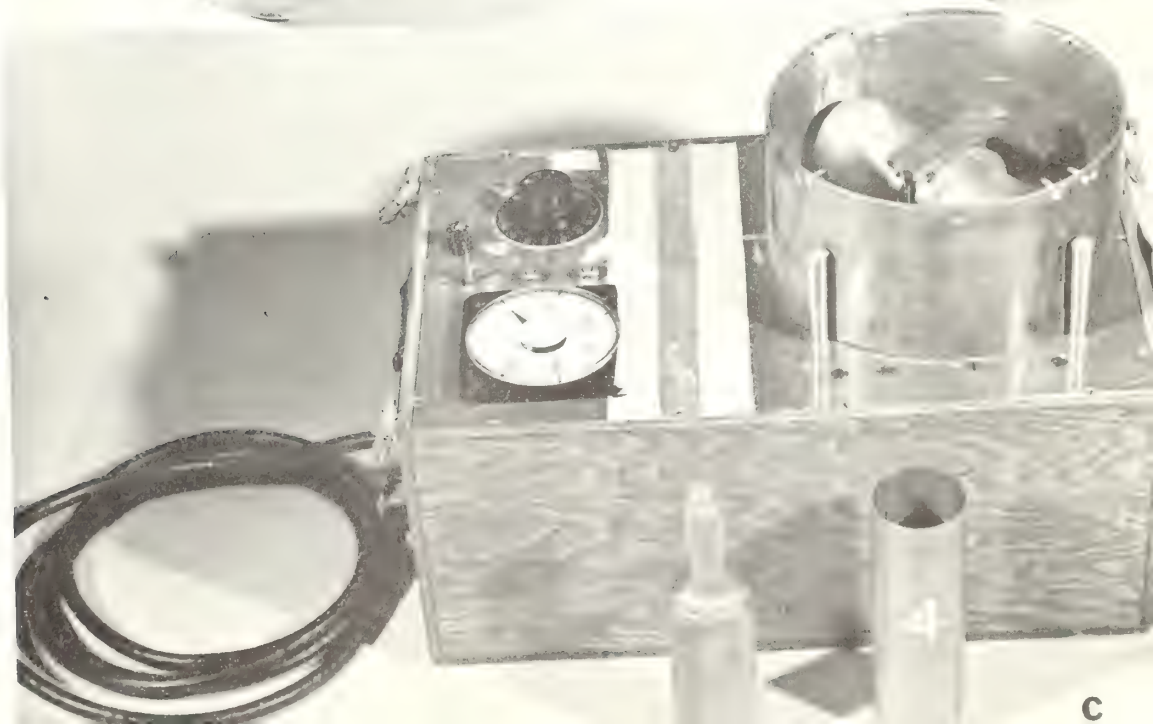


Figure 5.--Centrifugal or spin tester used to measure tensile strength:
A, Transferring sample from tube to tester;
B, Placing restraining yoke in position;
C, Shroud in place prior to test.

Strength was computed from the angular momentum at the time of failure (Bader et al. 1951, p. 11). The sample usually failed in the middle where the cross-sectional area was reduced by the restraining yoke. On a few occasions, however, there were flaws in the sample that caused failure near one end. In these cases, the data were not used. In general, this test offered relatively few problems—most of which were easy to detect—and the results were felt to be the best of the several strength tests.

Tensile strength of snow 14 days old, or younger, as measured with the spin tester, varied from 1.0 to 1712 gf cm^{-2}. The maximum value was 2100 gf cm^{-2} for a 26-day-old sample measured on January 18, 1968. Strength increased rapidly with density (fig. 7), but a fourfold range of strength for a given density was common.

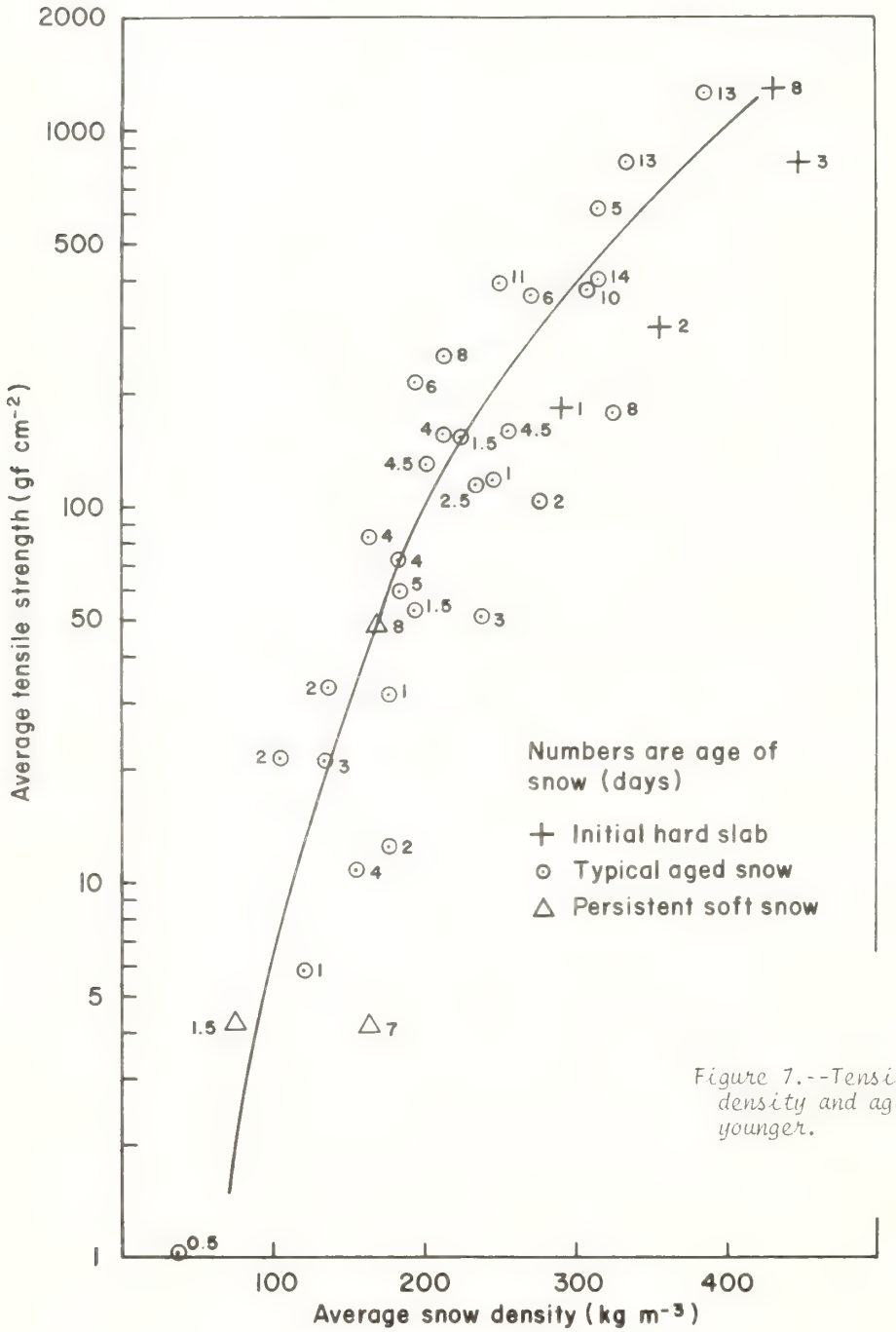


Figure 7.--Tensile strength as a function of density and age for snow 14 days old or younger.

There was a tendency for the younger snow of a given density to be weaker than the older snow of the same density, especially for densities of 200 kg m^{-3} and higher. Initial hard slab shows up in figure 7 as relatively weak, young snow of high density. For example, our data indicate snow with a density of 350 kg m^{-3} should have a tensile strength of 600 to 700 gf cm^{-2} rather than the 300 gf cm^{-2} strength measured on March 5, 1966 in 2-day-old initial hard slab.

The slopes of the regressions of tensile strength versus density appear the same for these data and those of de Quervain (1951), Roch (1966), Keeler and Weeks (1967), and Keeler (1968) (fig. 8). There is some displacement of the regressions, however, with the old, fine-grained snow of Keeler and Weeks (1967) being the strongest, and the fresh, fine-grained snow of Roch (1966) being the weakest for a given density.

In a series of controlled-temperature experiments, Roch (1966) showed an increase of tensile strength with a decrease in temperature. This amounted to about doubling the strength as temperature dropped from -2° to -40° C. Although no such trend could be detected in our field samples, which were mostly between -5° and -15° C., this should not be construed as contradictory evidence because our study was not designed to relate strength to temperature.

Two indexes of shear strength were measured. In the torque vane test, a cross-shaped vane was pushed from above to the desired depth in the snow and turned with a torque wrench (Mellor 1969, Radforth and Rush 1964, p. 17). This type of in situ test is widely used in soils work where it has proven to be well correlated with laboratory tests of strength (Hamilton 1959).

Torque vane shear strength was computed on the basis of the cylinder generated by the rotation of the vane. Although this was the fastest and easiest of the strength indexes to measure in the field, the tendency for the snow to fail in a "stick-slip" manner caused difficulties. Apparently what happens is that the snow just ahead of the vanes compacts when force is first applied, causing initial failure. As more force is applied, the cylinder of disturbed snow breaks free of its surroundings in ultimate failure. For our purposes, the force needed to cause ultimate failure was used to determine what we call torque vane strength. This value corresponds to the strongest snow in a layer as thick as the vane is long. For all but the toughest snow, we used a vane 3 inches long by 1.5 inches wide. In tough snow, a smaller vane, 2 x 1 inch, was used. Neither was satisfactory for new snow when densities were 100 kg m^{-3} or less. The torque vane was loaded at a rate of about 30° per second, and failure usually occurred in the first 1 to 1.5 seconds.

The correlation between tensile and torque vane strengths is good (fig. 9). The general trend, however, is much closer to 1:1 than it is to the 10:1 ratio found by Keeler and Weeks (1968).

The plot of torque vane strength as a function of age shows too much scatter to be helpful.

The second index of shear strength was determined with a spring balance and a small metal frame, 100 cm^2 in area, which was slightly broader in front than back (de Quervain 1951, Mellor 1969). The frame was pushed into the snow from above. Snow in front of it was cleared away, and the spring balance, attached to a hook on the frame, was pulled with a steady motion parallel to the top and bottom planes of the frame. This technique gave best results when the bottom of the frame was at the center of a uniform layer of weak snow, or at the boundary between two distinct layers. In the first case, the strength of the layer was measured; in the second, the strength of the bond between layers. Most of the readings reported here were made in the middle of layers rather than at layer boundaries. Data from this device are referred to hereafter as shear frame strengths.

Several difficulties were encountered while using the shear frame. In cases where a tough snow layer lay on top of a softer one, it was necessary to cut the tough snow with a knife and insert the frame in the cuts to avoid collapsing the softer layer or shattering the tough, brittle layer when inserting the frame. This procedure was also necessary for soft feltlike snow, which deforms under the weight of the frame. In other cases, deep, uniform layers of tough snow often fail along a curved rather than a plane surface.

Shear frame strength was appreciably less than any other strength index. This may, in part, reflect the tendency for some snows to fracture when the frame is inserted unless knife cuts are made. Keeler and Weeks (1967) found torque vane and shear frame strengths to be equal. We found them to be equal only for very weak snow (<10 gf cm^{-2}, fig. 10); at higher strengths, torque vane strengths were 3 to 4 times shear frame strengths.

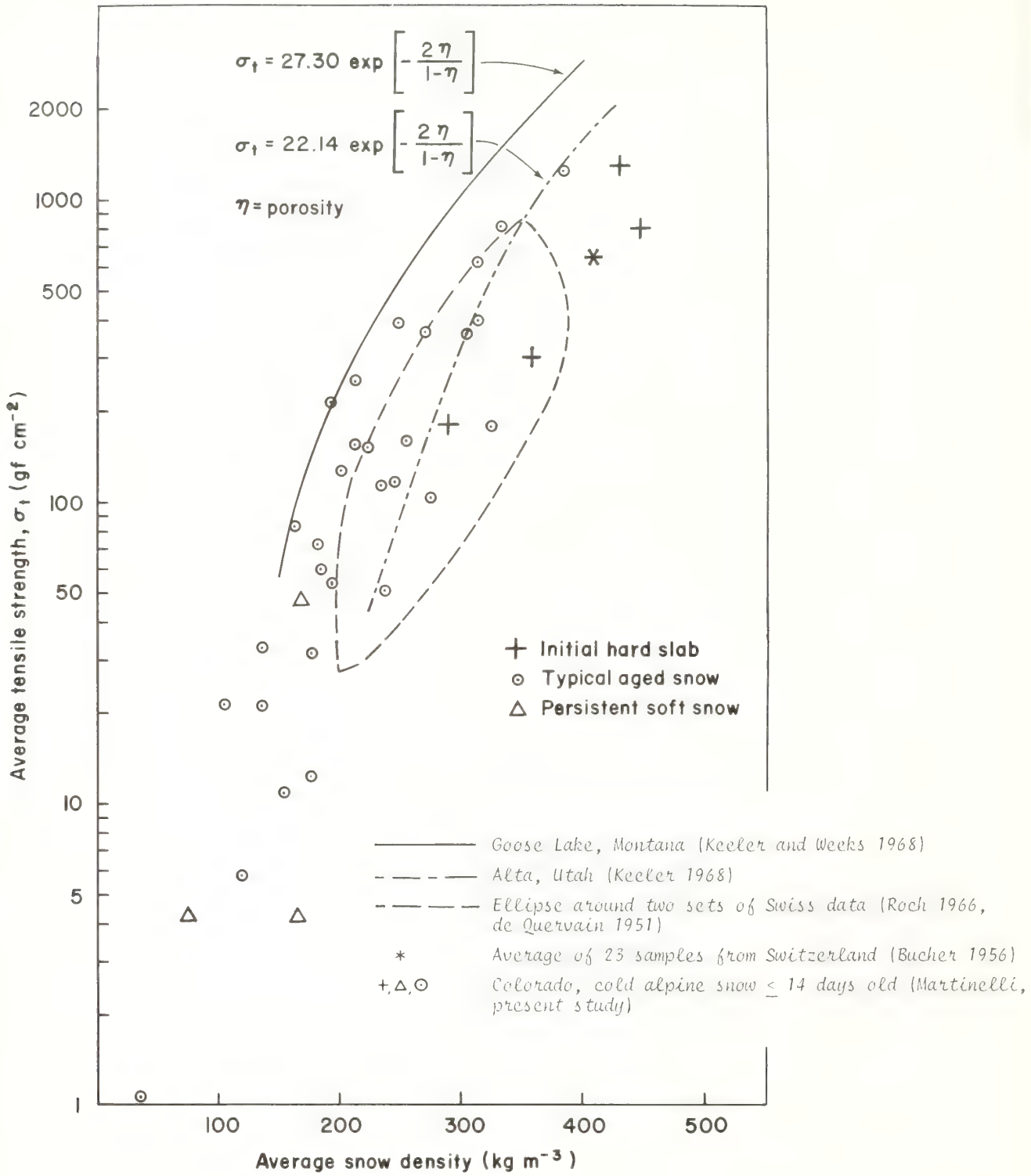


Figure 8.--Average tensile strength as measured by spin tester versus density.

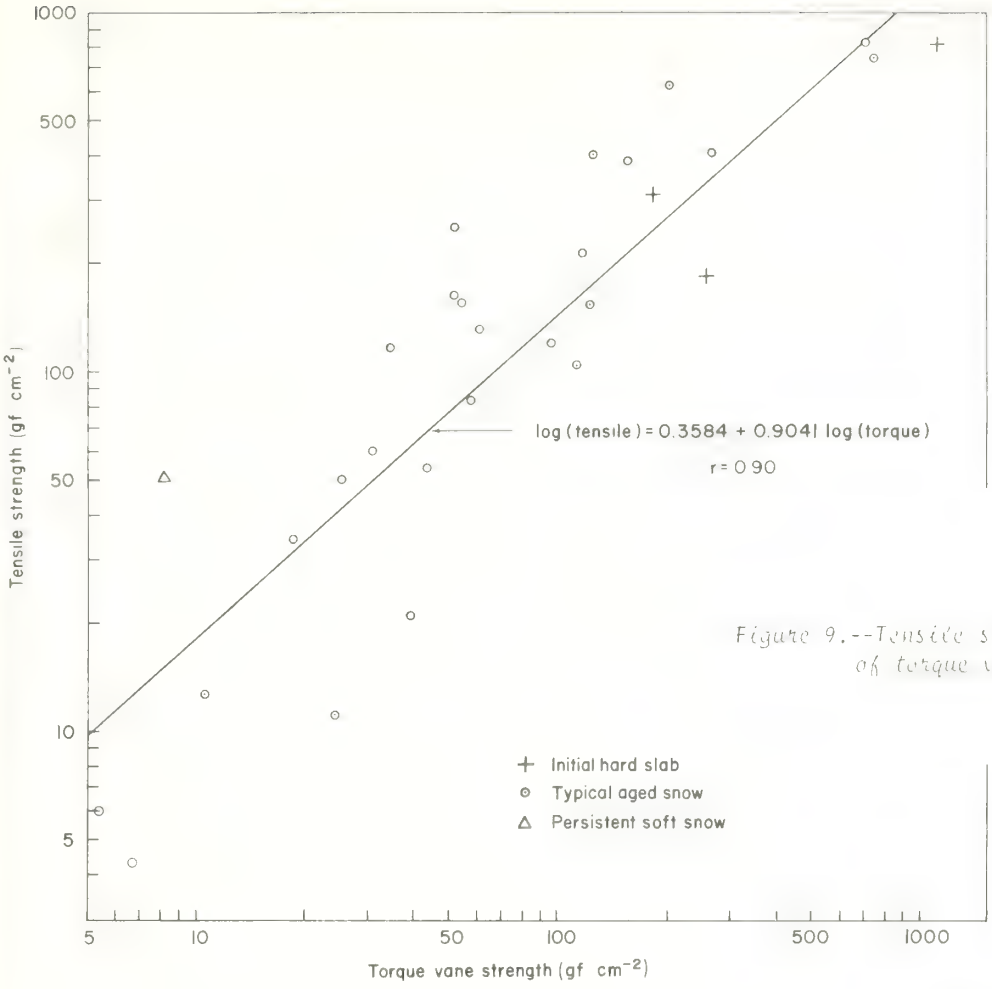


Figure 9.--Tensile strength as a function of torque vane strength.

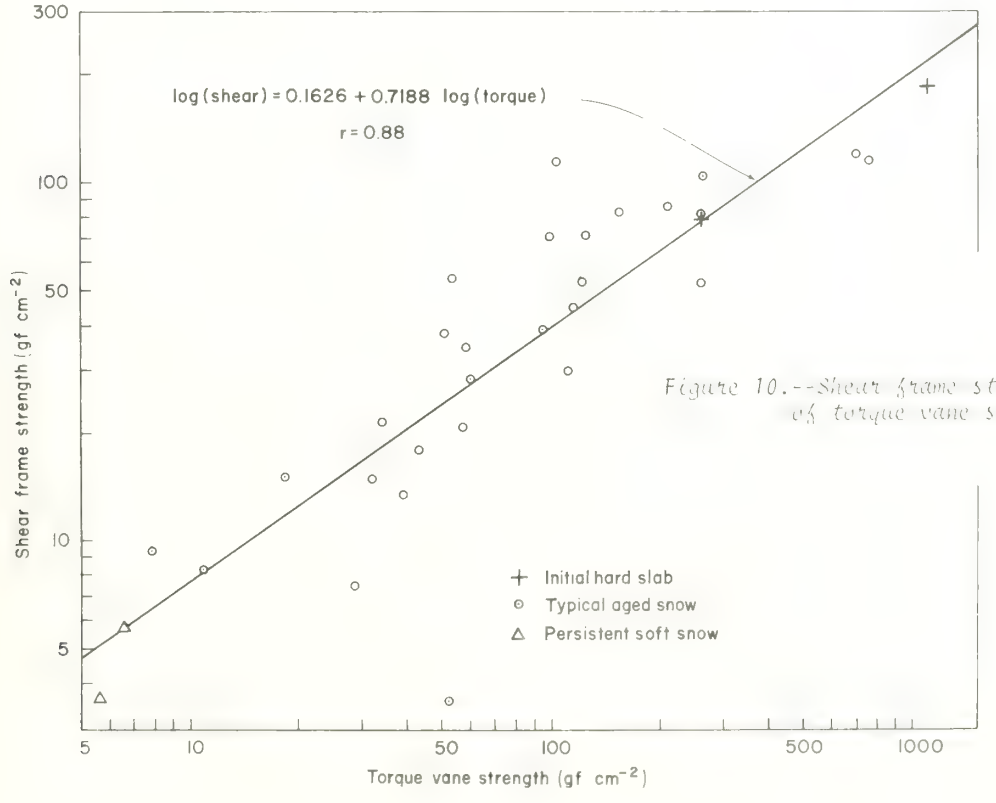


Figure 10.--Shear frame strength as a function of torque vane strength.

The regression between tensile and shear frame strengths (fig. 11) seems to have a time or age dependency (fig. 12). For example, tensile strength is about three times shear frame strength for snow 2 to 3 days old, but it is 5.5 to 6 times shear frame strength for snow 10 days old. There is also a variation with the strength of the snow. Tensile strength is 5 or 6 times shear strength for strong snow, but less than twice shear frame strength for weak snow (fig. 13).

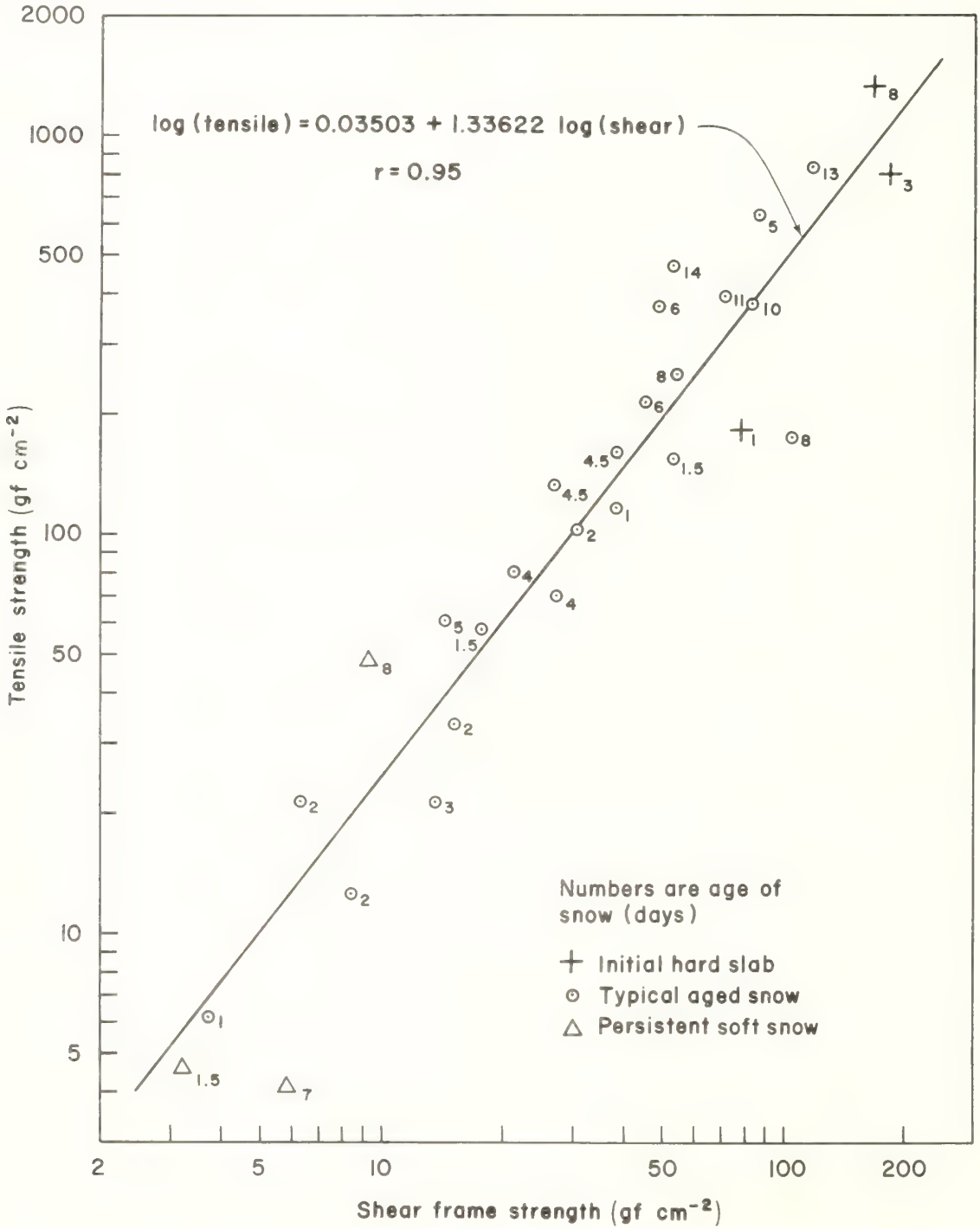


Figure 11.--Tensile strength as a function of shear frame strength.

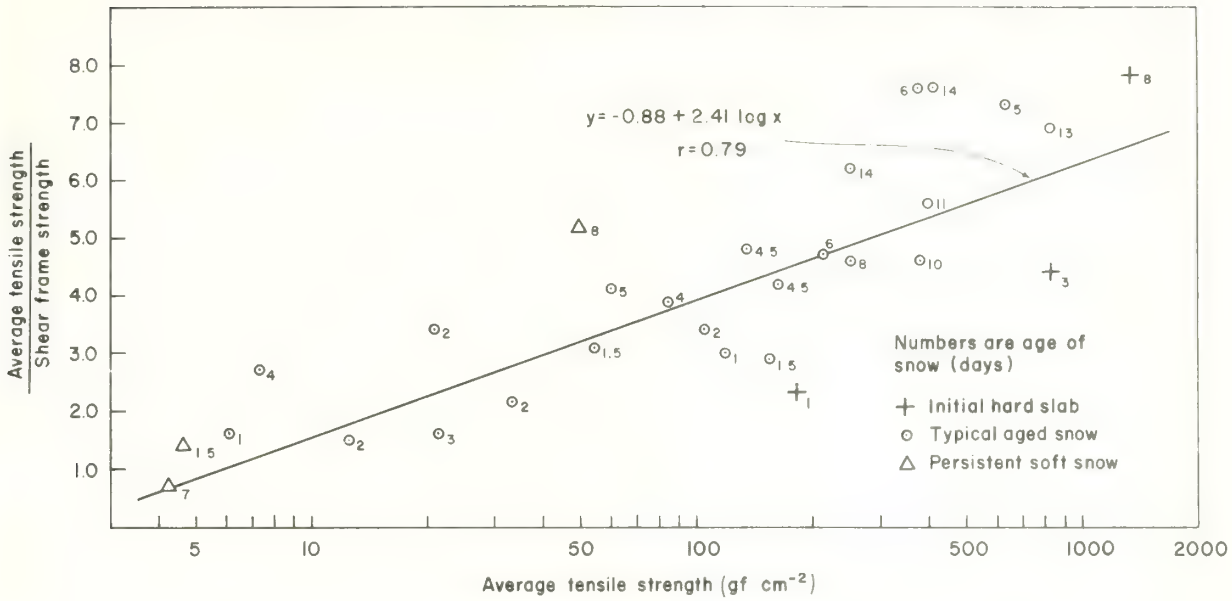

Average tensile strength / Shear frame strength
Average tensile strength (gf cm^{-2})
y = -0.88 + 2.41 log x
r = 0.79
Numbers are age of snow (days)
Initial hard slab
Typical aged snow
Persistent soft snow

Figure 12.--Average tensile strength/shear frame strength as a function of age. Dates are given for a few points to facilitate reference to the appendix.

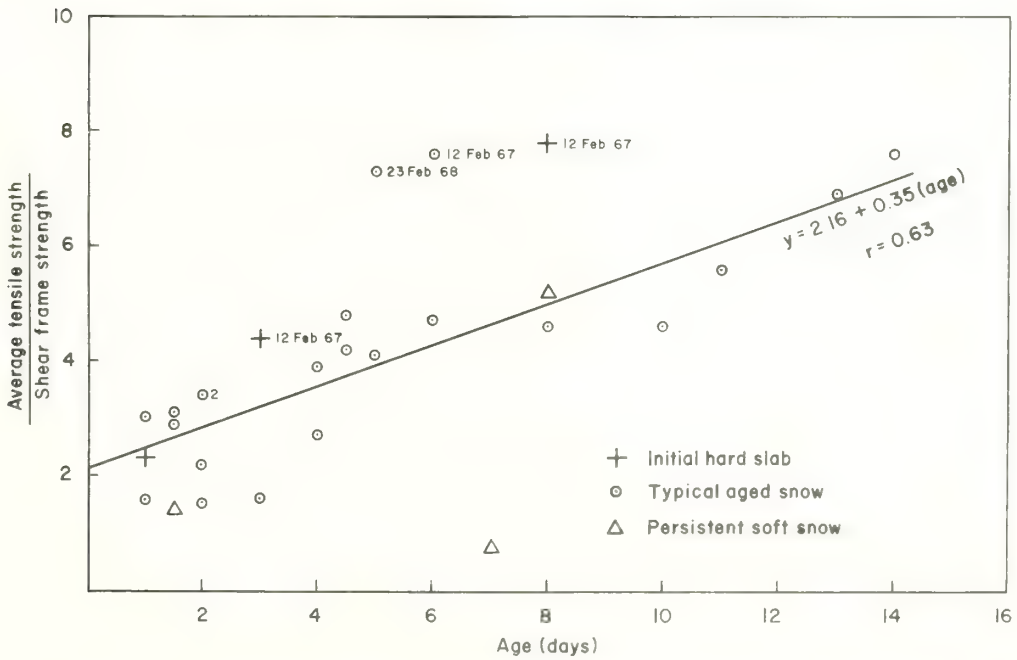


Figure 13.--Average tensile strength/shear frame strength as a function of average tensile strength.

Roch (1966) also showed that the relationship between shear and tensile strengths (as measured by the shear frame and spin tester) varies greatly for strong and weak layers. He reported tensile strength to be about 5 times shear strength in strong layers, but no greater than twice shear strength for weak layers. Keeler (1968), on the other hand, reported tensile strength to be 6 to 6.5 times shear strength for snow at Alta, Utah, and Goose Lake, Montana, without qualifications or reservations.

All strength measures showed the expected increase as grain type changed from settled powder (type b) to fine-grained old snow (type d). There

was also a rapid increase in all strengths as density increased. The apparent increase in strength with age may be only a reflection of the strong dependency between density and age, but it is more likely to be a function of the number and strength of the grain-to-grain bonds.

Ram Resistance

The technique for determining the hardness profile of a snow cover with an impact penetrometer was first described by Haefeli (1954), and has been widely used since (Mellor 1969). A sectional rod with a 60° conical tip, 4 cm in diameter, is driven into the snow by a falling weight. Ram resistance is one of the easiest snow properties to measure in the field because no pit is needed. Data presented here were computed from the equation:

$$R = \frac{w_1 h x}{\Delta E} + w_2$$

where

R = ram resistance (kg)
w_2 = total weight of hammer plus penetrometer (kg)
w_1 = weight of hammer (kg)
h = height from which hammer is dropped (cm)
x = number of drops
ΔE = penetration of point for x blows (cm)

No correction was made for the energy of impact or coefficient of restitution as mentioned by Haefeli (1954, p. 128) and Waterhouse (1966). Although these corrections may be appreciable under certain conditions, they have usually been ignored; hence uncorrected data are easier to compare with those already published.

Ram resistance and density were available not only from the alpine study site (called the Roll), but also from a nearby small opening in the timber (called Q-12 Park).

A least squares fit of the form

$$\log R = a + b\hat{\rho}$$

where

R = ram resistance in kg
$\hat{\rho}$ = density in kg m^{-3}

was computed for both sets of data excluding depth hoar, isothermal snow, and ram numbers of 1. The results confirm the positive correlation between ram number and density (fig. 14) previously reported for polar snow by Bull (1956) and for seasonal snows by Keeler and Weeks (1967, 1968). Table 3 shows a reasonably good agreement for all the data except that from Q-12 Park. Density is not so well correlated with ram number at Q-12 Park as at the other sites, nor does the ram resistance increase as much per unit increase in density. The lower strength at Q-12 Park is attributed to protection from the wind. All the other sites in table 3 were considerably more exposed than Q-12 Park.

For prediction of density, the regression for the 14-day and younger cold snow from the Roll would be

$$\hat{\rho} = 131.0 + 130 \log R,$$

that for cold snow no more than 1 month old from the sheltered Q-12 Park would be

$$\hat{\rho} = 209 + 86 \log R,$$

and for cold snow in Q-12 Park no more than 4 months old, it would be

$$\hat{\rho} = 213 + 108 \log R$$

A covariance analysis of the Roll (112 points) and the 1 month and younger data from Q-12 Park (64 points) indicated the intercepts were significantly different at the 1 percent level, and the regression coefficients were significantly different at the 5 but not at the 1 percent level.

This analysis also showed that, for a given ram resistance, alpine snow had a lower density than snow from a sheltered opening, especially for ram numbers below about 15 kg. Thus alpine snow appears to be stronger for a given density than snow from a sheltered opening—provided one accepts ram resistance as an index of strength.

Although the exact relationship between strength and ram resistance is not known (de Quervain 1951), figure 15 illustrates the good correlation between ram resistance and tensile strength. This relation can be improved by making allowances for the age of the snow. For ram resistance between 5 and 30 kg, the tensile strength of snow 4 days old and older is 1.5 times that of younger snow with the same ram resistance.

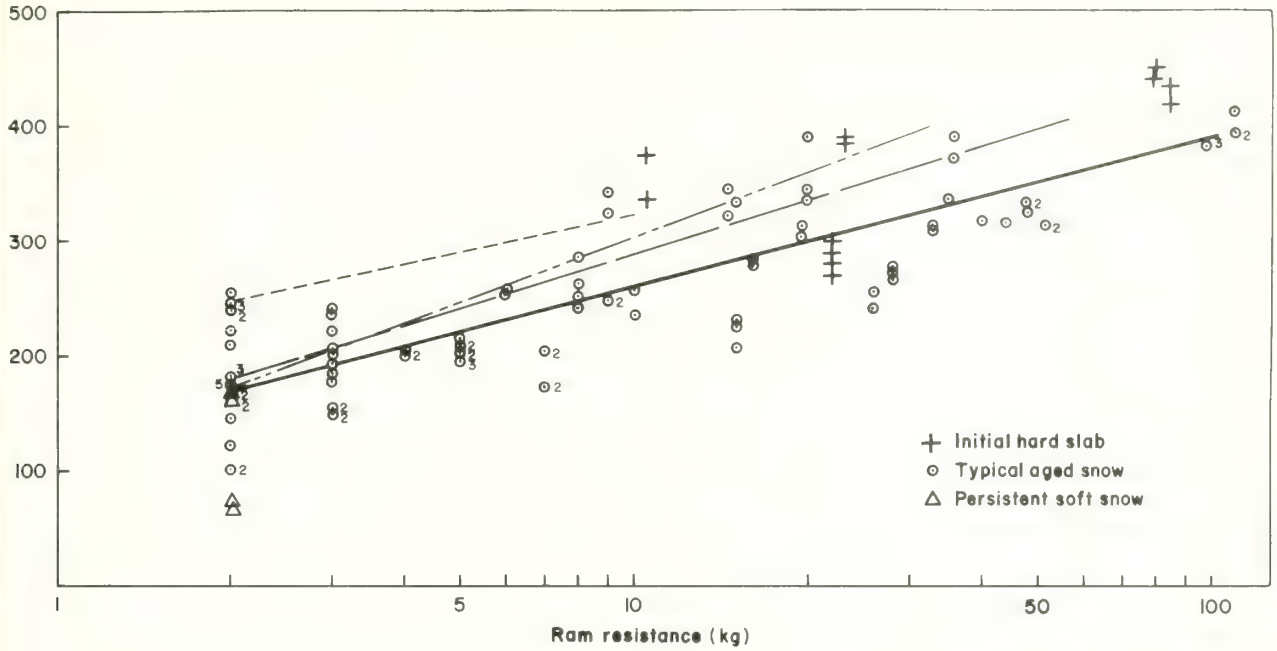


Figure 14.--Density as a function of ram resistance. All data points are for this study. Numbers indicate symbols that represent more than one point.

— — — — *Greenland snow (Bull 1956)*

—— — — —— *Goose Lake, Montana, dry snow (Keeler and Weeks 1968)*

——— ——— *Q-12 Park, near study site. Cold snow; all ages; depth hoar and ram resistance of 1 kg excluded.*

———— } *Cold alpine snow ≤ 14 days old (Martinelli, present study)*
+, △, ⊙ }

Table 3.--Summary of regression and correlation coefficients for several sets of data fitted to the regression

$$\log R = a + b\hat{\rho}$$

Source	a	b	Correlation coefficient (r)	Age of snow	Density range
					kg m^{-3}
Bull (1956)	-0.6107	0.00531	0.80		
Keeler & Weeks (1967)	- .8446	.00640	.94	<4 months	100 - 510
Keeler (1968)	- .7482	.00599	.89	<4 months	150 - 430
This Study:					
Roll	- .428	.00543	.84	≤14 days	40 - 450
Q-12 Park	- .305	.00343	.54	≤1 month	100 - 390
Q-12 Park	- .463	.00421	.68	≤4 months	100 - 430

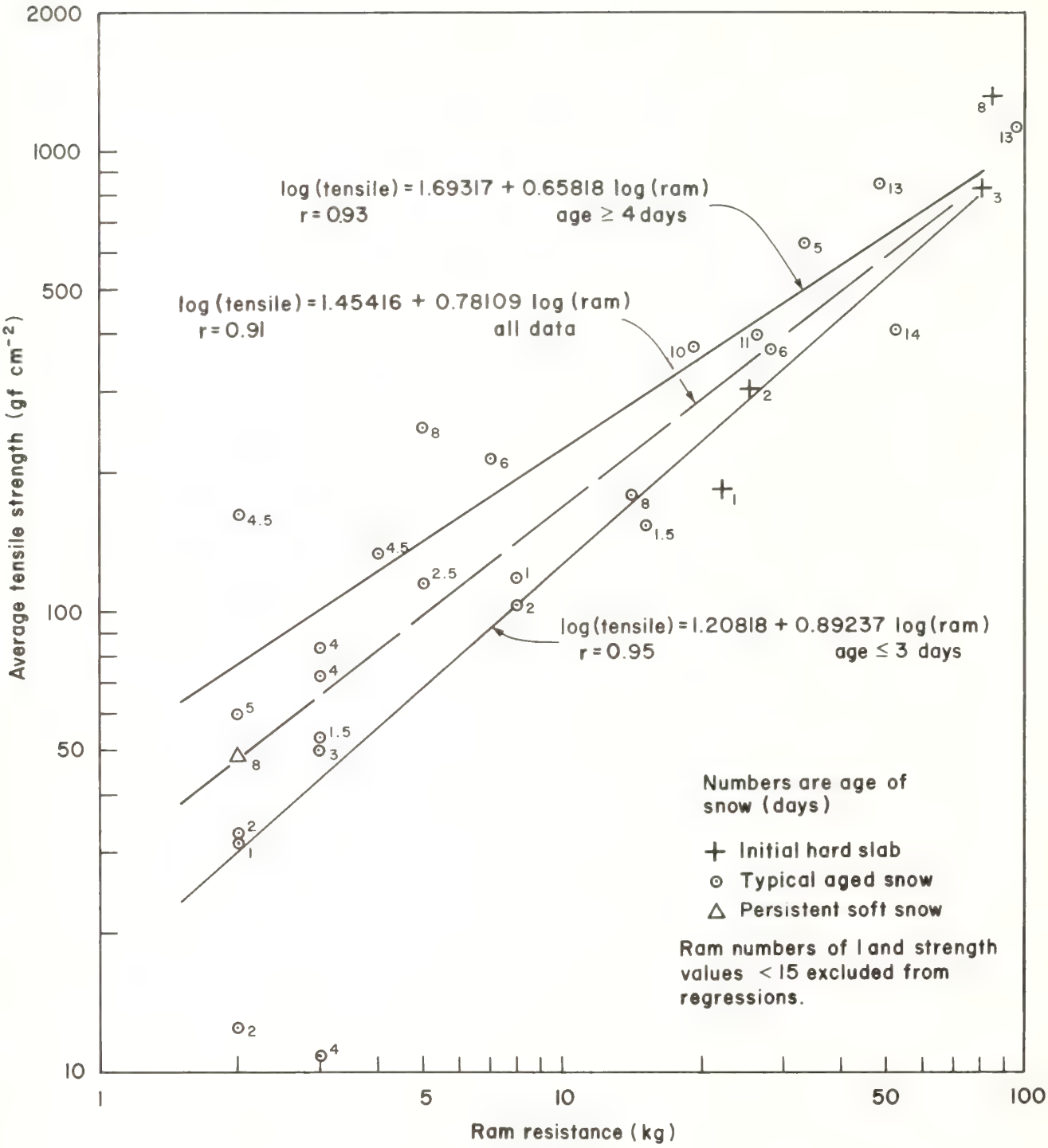


Figure 15.--Average tensile strength as a function of ram resistance and age.

Although our data do not justify further refinement of the ram resistance-time relationship, Hobbs (1965) found a linear log-log relation between ram resistance and time for artificially compacted snow, using data from Wuori (1963).

These discussions of ram resistance versus strength have been confined to tensile strength for the sake of brevity. Torque vane and shear frame strength follow the same general patterns, but with more scatter.

Any consideration of ram resistance is handicapped by the lack of sensitivity at low ram resistances. Ram resistances below 1 kg cannot be measured with existing instruments, and readings below 3 to 5 kg are not very accurate. A lightweight rammsonde with the same geometry as the original instrument but capable of readings as low as 0.1 kg is now being field tested by the U.S. Forest Service (Perla 1969). It should be very useful in soft, fresh snow.

Air Permeability

The coefficient of air permeability (K) reported here is defined by the equation

$$K = \frac{QL}{A\Delta P} = \frac{v}{i} \qquad (1)$$

where

- Q = volume of air ($cm^3\ sec^{-1}$)
- L = length of snow sample in the direction of airflow (cm)
- A = area of snow sample perpendicular to flow direction (cm^2)
- ΔP = pressure differential (cm of water)
- v = airflow velocity = Q/A ($cm\ sec^{-1}$)
- i = pressure gradient = $\frac{\Delta P}{L}$ (cm of water per cm of length of sample)

The units of K are $cm^2\ sec^{-1}$ $(cm\ of\ water)^{-1}$. Some authors have erroneously canceled cm with $(cm\ of\ water)^{-1}$ and reported K in units of $cm\ sec^{-1}$. For comparative purposes, however, the numerical values of the K presented here can be compared directly to those reported as $cm\ sec^{-1}$. Our data were not corrected for the deviation of temperature from 0° C., nor were they adjusted back to sea level elevation.

The following test procedure was used to determine air permeability and change of permeability upon compaction of the snow:

1. A sample tube with the undisturbed snow still in it was placed in a holder that formed an airtight seal around the outside of the tube.
2. A vacuum pump created a pressure differential that pulled air through the sample.
3. Three flow rates and corresponding pressure drops were recorded for each sample.
4. Permeability was computed for these three sets of data.
5. The sample tube was removed from the holder, a rubber cap placed over one end, and the snow was compacted with a wooden ram.
6. The cap was removed from the tube, which was put back into the holder and subjected to a pressure differential.
7. Pressure drop and airflow through the compacted sample were recorded.
8. A new permeability was computed for the compacted sample.
9. Steps 5, 6, 7, and 8 were repeated for five compactions.
10. A graph of the ratio of permeability to porosity ($\frac{K}{n}$) as a function of permeability (K) was plotted for each sample.

One of the three airflow rates used in step 3 (usually the highest) was used in steps 6 and 9. Sample tubes were the standard SIPRE density samplers. Pressure differential was measured on a differential capacitance meter with a range of 0.001 to 30.0 mm of mercury. Airflow was measured by a floating sphere, three-flat-faces type flowmeter with a range of 0.009 to 0.03 $cm\ sec^{-1}$ at 11,300 feet elevation.

Airflow velocities(v) were between 0.001 and 0.021 $cm\ sec^{-1}$, and pressure gradients (i) were mostly between 0.02×10^{-3} and 20.0×10^{-3} cm water/cm length of sample. These were kept several orders of magnitude lower than those commonly used (Bader 1954, Bender 1957, Ishida and Shimizu 1958, Ramseier 1963) to assure flow in the "laminar" range. Because of the lower velocities and pressure gradients, however, other problems, presumably associated with low flows through porous media, were encountered.

This technique was tedious, and the compaction in step 5 certainly changed the structure of the snow in a far different manner than the change produced by tapping or shaking a noncohesive granular material like sand or gravel. In spite of these difficulties, duplicate samples of a pair usually gave consistent results.

The coefficient of air permeability was found to vary with pressure differential and flow rate, although the velocities were well below the "turbulent" range:

Change in permeability as flow rate was increased	Percentage of total samples
Remained the same	42
Increased	30
Decreased	8
Decreased, then increased	10
Other	10

These changes in permeability with flow rate were determined on 61 samples of alpine snow ≤14 days old. Instrumentation error in determining permeability was approximately 15 percent.

There was no unique permeability; one of the three values computed in step 4 was selected to describe the sample. The permeability corresponding to the airflow rate used in steps 7 and 9, usually the highest applied to the undisturbed sample, is the one reported here.

For snow 2 weeks or less in age, the coefficient of air permeability (K) varied from 7.5 to 313 $cm^2\ sec^{-1}$ (cm of water)$^{-1}$. About 70 percent of the samples had permeabilities between 10 and 30 $cm^2\ sec^{-1}$ (cm of water)$^{-1}$. The relatively few samples older than 2 weeks or of unknown age had K's between 15 and 48 $cm^2\ sec^{-1}$ (cm of water)$^{-1}$. These values are about one order of magnitude lower than those often quoted for air velocities up to 5 to 10 cm sec^{-1}.

The low permeability values and the variation of permeability with flow rate may both result from the low flow rates used. Although much is written about avoiding high flow rates and the resulting "turbulent flow," little mention is made of the problems associated with low flow rates in granular materials except when pore spaces in the material approach the mean free path of air molecules (Scheidegger 1960).

Recently, Langfelder and coworkers (1968) reported soils studies where permeability increased with an increase in pressure gradient. They also showed a nonlinear relation between flow rates and pressure gradient for clay soils when flow rates were not much greater than ours. The threshold gradient for nonlinearity was different for different soils. If a similar shifting threshold gradient can be found for cold snow, the magnitude of the threshold may be more indicative of snow structure than such things as simple air permeability upon compaction. Such a discovery would also help explain the phenomena, since several of the possible explanations offered by Langfelder and coworkers (1968) were based upon the presence of free water in the sample, which would not be present in cold snow.

Figure 16, which follows the example of Ishida and Shimizu (1958), shows permeability is not a well-defined function of density and grain type. Even within a grain type, the variation in permeability with density is so large as to make the relationship valueless. The slightly metamorphosed, type b, snow had the greatest range of permeability. Low permeabilities with moderate to high densities were typical of the fine-grained old snow (type d), while coarser-grained old snow (e or d) had moderate to high (30-110 $cm^2\ sec^{-1}$ (cm of water)$^{-1}$) permeability with high density (300-500 kg m^{-3}). The bd mixture resembled type b snow more than type d in permeability and density.

The permeabilities found in this study fall into the lower edge or below the diagrams of permeability as a function of porosity given by Bader (1954, 1962) and Keeler (1968) (fig. 17). Our initial hard slab had not only lower permeability but also lower porosity (higher density) than the wind slab indicated by previous workers.

The most common analysis of air permeability for snow is based on the empirical expression of permeability (K) as a function of porosity (n) developed by Bader (1954, 1962) and later used by Bender (1957) and Ramseier (1963).

$$K = \frac{anN}{N-n} \text{ or } \frac{K}{n} = a + \frac{1}{N} K \qquad (2)$$

The constants N and a are determined graphically by plotting K/n against K for several porosities obtained by compacting each sample. $\frac{1}{N}$ is the slope and a is the K/n axis intercept for the linear part of the line.

N is called virtual porosity and is usually interpreted as the loosest possible packing for the texture. The ratio N/n is reported to be 1.063 (Bender 1957) to 1.058 (Bader 1954) for normal metamorphosed snow, and to approach 1.1 (Bader 1954) to 1.2 (Bender 1957) for wind-packed snow. With time, metamorphism is said to change the wind-packed ratio back to the "normal" ratio. The con-

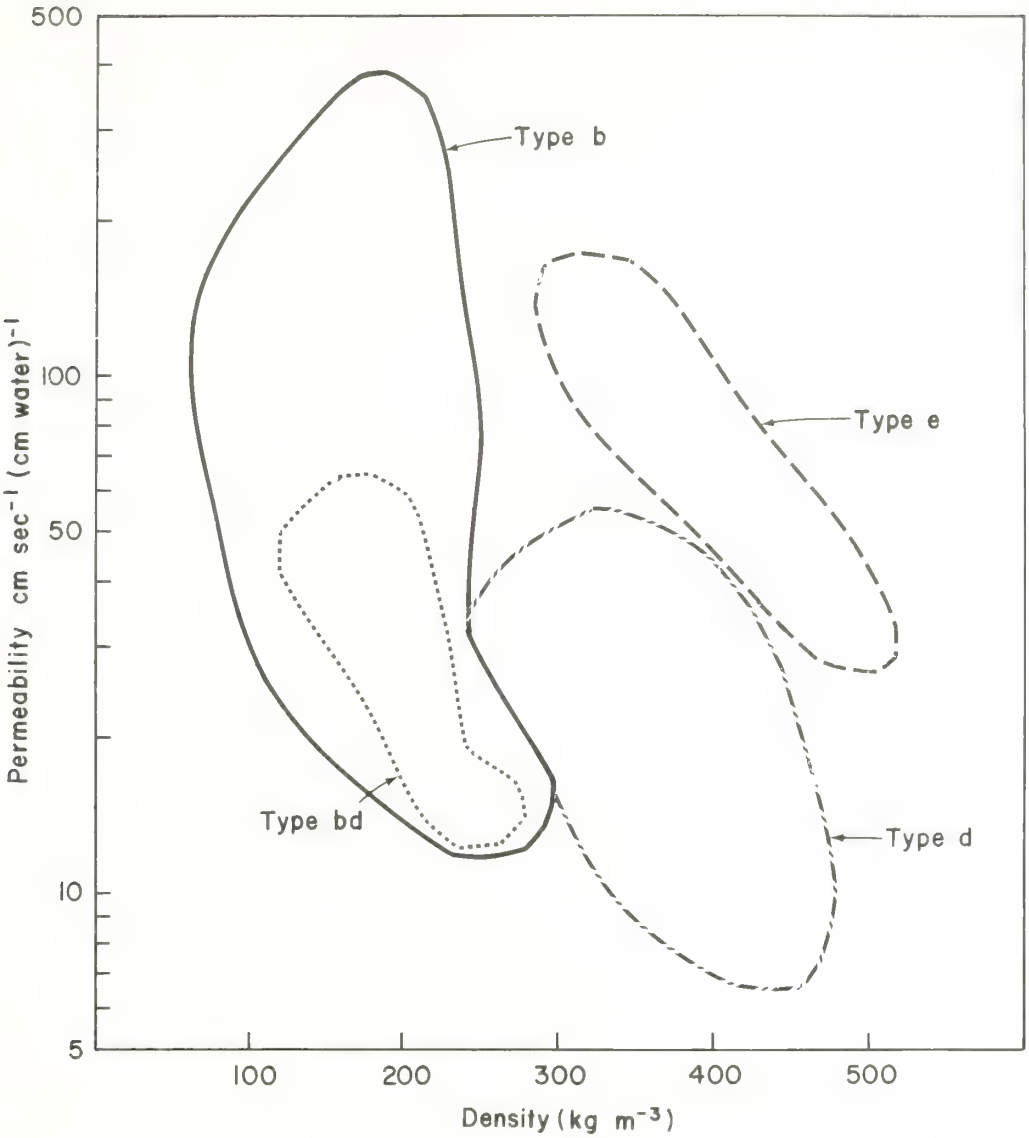


Figure 16.--Permeability to air as a function of density with grain types delineated.

stant "a" depends mostly on grain size. Bender (1957) suggests the relation is approximately

$$a = 16.8d^{1.63} \qquad (3)$$

where d is grain diameter in mm.

The overall average of N/n for our data was 1.0554 for samples 14 days or younger and 1.0617 for all samples (tables 4 and 5). These agree well with the "normal" ratios of 1.063 and 1.058 reported earlier. The averages for initial hard slab, typical aged snow, and persistent soft snow were 1.08, 1.03, and 1.02, respectively (see table 6). These agree in principle, if not in absolute values, with the idea of larger ratios reflecting greater wind action.

Virtual porosity varied from 0.943 for very weak new snow to 0.444 for heavily metamorphosed old snow. Bender (1957) reports values from 0.92 to less than 0.50.

The above analyses were interesting for comparative purposes, but were of little diagnostic value. Several additional analyses were tried to see if more helpful relationships could be found.

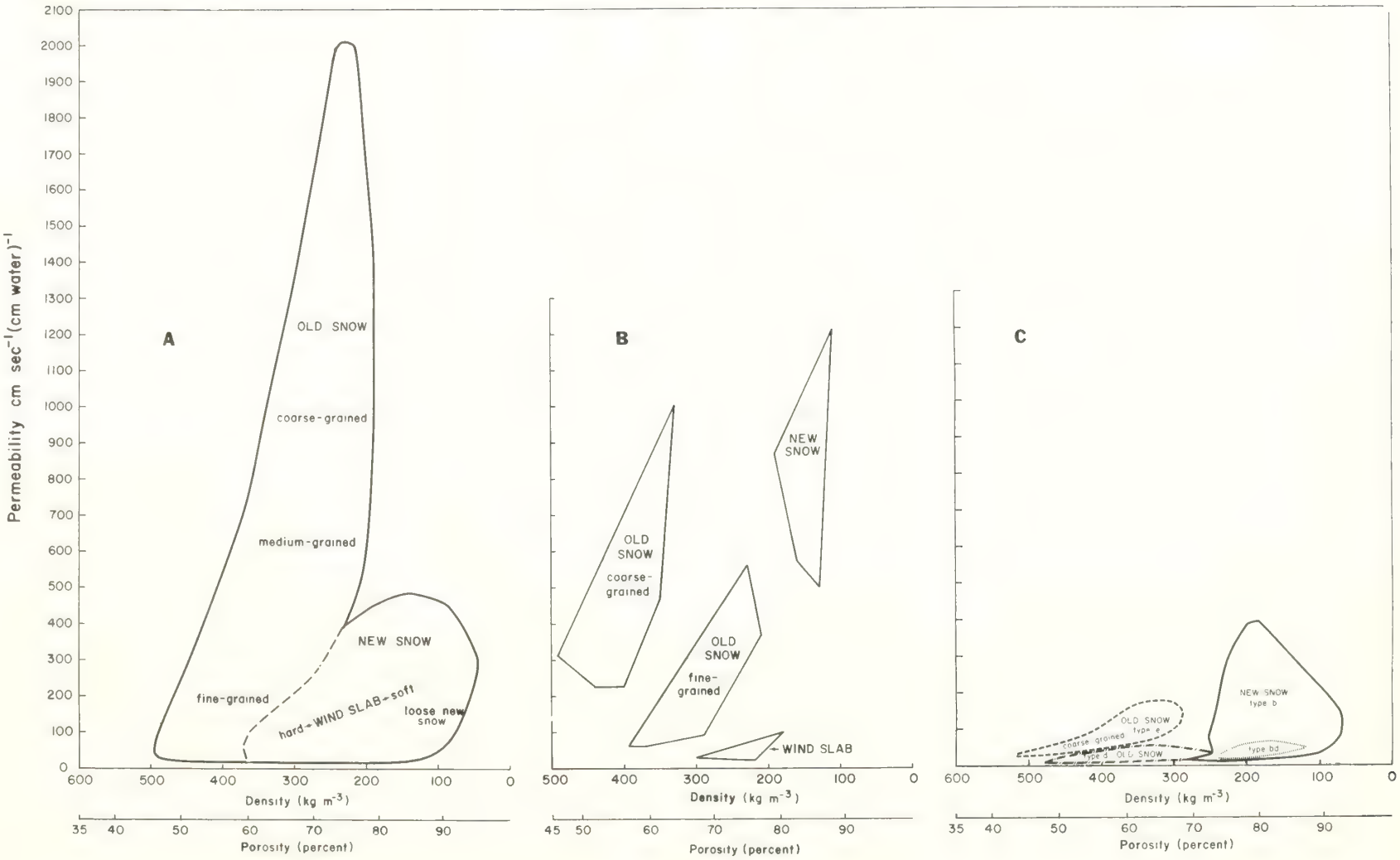


Figure 17.--Permeability to air as a function of porosity (density) after (A) Bader (1954), (B) Keeler (1968), and (C) this study.

Table 4.--Average N/n for snow 14 days old or younger, by sampling dates, where N = virtual porosity and n = actual porosity

Sampling date	N/n	Number of samples	Sampling date	N/n	Number of samples
20 Feb 68[1/]	1.0155	1	6 Jan 67	1.0551	4
13 Dec 66[2/]	1.0199	1	23 Feb 68	1.0558	8
3-4 Jan 67[1/]	1.0212	5	1 Feb 67	1.0600	6
15 Jan 67	1.0375	4	12 Feb 67	1.0646	10
2 Feb 68[1/]	1.0381	4	3-4 Feb 65	1.0742	6
28-29 Jan 65	1.0428	2	17 Jan 68	1.1657	2
29-30 Apr 68	1.0454	2	Average or total	1.0554	60
31 Jan 67[1/]	1.0514	5			

Additional samples less than 1.0:
[1/] one.
[2/] three.

Table 5.--Average N/n by age of snow for all data, where N = virtual porosity and n = actual porosity

Snow age (Days)	N/n			Number of samples
	Average	Maximum	Minimum	
0-3	1.0420	1.1176	1.0000	[1/] 24
4-7	1.0556	1.0957	1.0066	[2/] 21
8-14	1.0767	1.2245	1.0083	[3/] 15
≥15 (or unknown)	1.0713	1.2438	1.0035	[1/] 39
Overall average	1.0617			99

Additional samples less than 1.0:
[1/] two.
[2/] four.
[3/] one.

In the first analysis, tensile strength was plotted against density with permeability classes indicated. This added nothing to the previous plot of tensile strength against density. However, a rearrangement of the same three variables to show permeability as a function of density with tensile strengths identified showed a very interesting pattern (fig. 18).

The use of permeability helped to clarify some of the scatter in the strength-density relation. For any given snow density there is apparently some intermediate permeability above and below which strength decreases. The axis of this "optimum permeability" sloped down and to the right, indicating lower optimum permeabilities for higher densities. To a large extent this axis also separated the older from the younger snow. Since permeability is usually considered an index of snow texture, figure 18 suggests that the strength of snow of a given density is greater for a certain textural arrangement than for any other. One explanation of the relationships shown in figure 18 hinges on the fact that snow of a given density can vary greatly in texture, which is generally defined as the spatial arrangement of grain centers and intergranular voids. A highly uniform texture with good grain-to-grain bonding and small, well-distributed flaws will have the maximum strength and intermediate permeability found along the axis of "optimum permeability." A change in texture toward larger grains, few and weaker bonds, and larger flaws will result in the weaker and more permeable snow found above the axis of "optimum permeability." On the other hand, a change from a highly uniform texture toward finer grains and a concentration of small, partially alined, but not necessarily communicating flaws will result in the

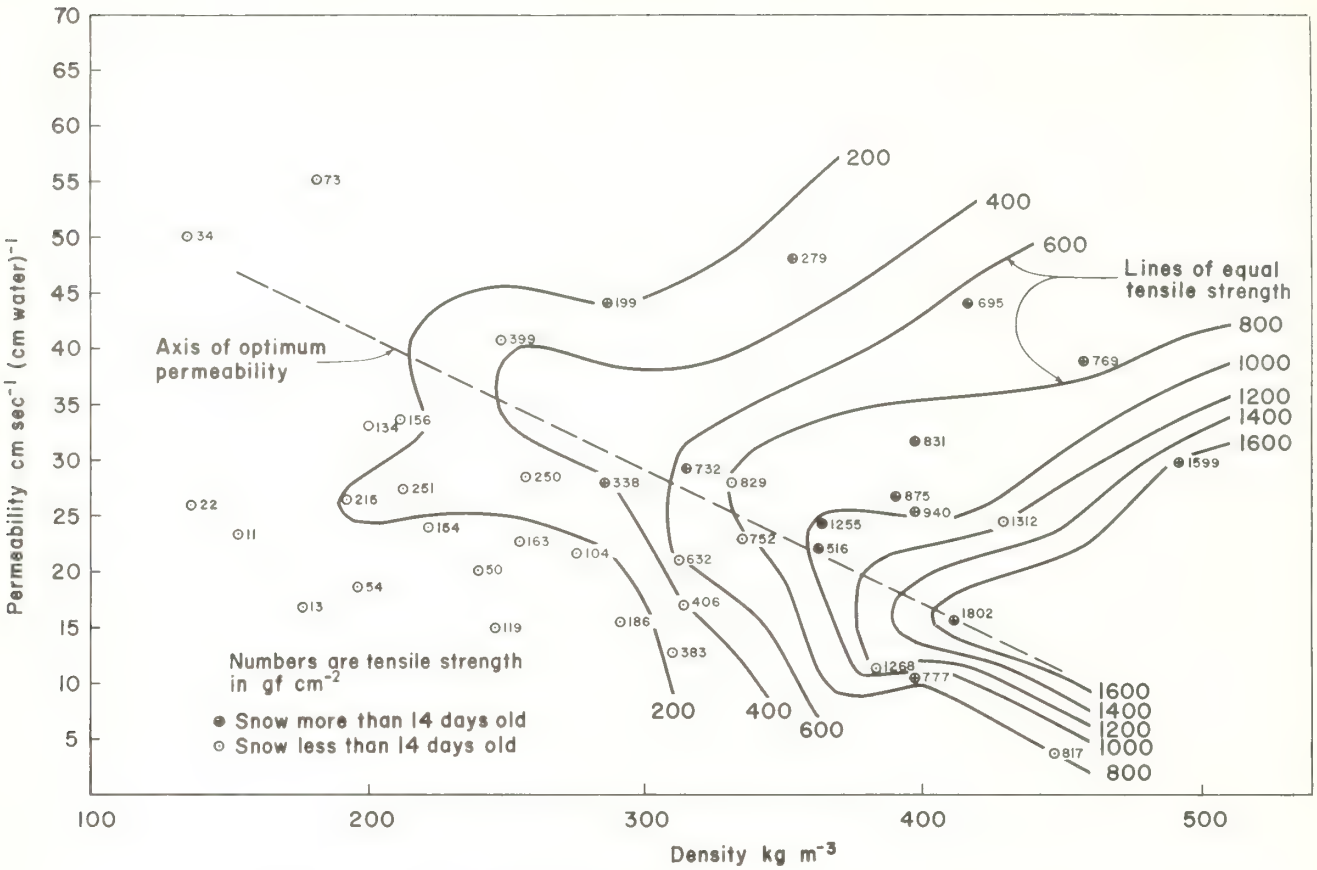


Figure 18.--Tensile strength as a function of density and air permeability; snow age not limited to 14 days or younger.

lower strength and relatively low permeability found below the axis of "optimum permeability." The slope of this axis toward lower permeability as density increases could be the result of a higher proportion of ice per unit area for a given texture rather than a change in texture. In spite of the formidable difficulties in making detailed measurements of the size, shape, and arrangement of grains and intergranular spaces, there is no other immediate prospect for a direct check of how these features actually relate to permeability and strength.

Snow Cover Properties as Related to Weather Conditions

Weather conditions during and following deposition of 17 snow layers are summarized (table 6) in an attempt to isolate the conditions that caused unusual density, strength, and hardness of the snow. Fifteen layers 3 days or less in age and two about twice that age were selected for study. Based on the density-age relationship discussed earlier in this paper, 3 of the layers were initial hard slab, 11 were typical aged snow, and 3 were persistent soft snow.

Hard slab has generally been considered the product of strong winds and low temperatures. Our limited sample tends to confirm this idea.

When initial hard slab was being deposited during our studies, winds averaged 1.5 times those when more typical deposition was taking place, and 2 times those during the deposition of persistent soft snow. Thus, high winds appear correlated to hard slab formation.

Average air temperatures during deposition decreased from periods of persistent soft snow, to typical aged snow, to initial hard slab. There was

Table 6.--Summary of weather and snow conditions for 17 snow layers in the alpine zone of Colorado

Date	Time of deposition	WEATHER CONDITIONS														TEST CONDITIONS						
		During deposition										After deposition										
		Wind					Average air temperature	Precipitation	Accumulated snow	Drift Ratio	Wind			Average air temperature	Subsequent precipitation until pit was dug	Date snow pit was dug	Age	Density	Temperature	Ram No.	Tensile strength	Rep. shear failure	Note
		Average speed	Duration	Prevailing direction	Maximum--						Average speed	Duration	Prevailing direction									
					hr.	hr.																
		mph	hrs		mph	mph	°F	cm	cm		mph	hrs		°F	cm		hours	gm/cm³	°F		kg/cm²		
TYPICAL AGED SNOW--3 DAYS OLD OR YOUNGER																						
[illegible] Jan 67	1700-0600	18.5	14	NW	24	21	10	0.051	0.716	14	9.6	1	Var	12	0.000	4 Jan 67	36?	[illegible]	- 1.5	--	1	[illegible]
[illegible] Dec 66	0800-1100	7.8	4	--	13	--	26	.305	.718	2	--	--	--	28	1.340	7 Dec 66	1.0	119.6	- [illegible]	1	6	--	--
19 Feb 68[1]	0030-2400	17.2	24	NW	21	20	18	1.420	7.370	5	11.8	9	NW	20	.051	20 Feb 68	1.0	245.5	- [illegible]	4	219	[illegible]	1.[illegible]
0[illegible] Jan-1 Feb 68	1000-0900	7.6	23	WNW	24	16	8	.686	3.090	4	9.6	25	NNW	5	.051	1 Feb 68	1.5	230.7	-26.0	13	154	[illegible]	1.[illegible]
20 Feb 68[2]	[illegible]-2400	13.1	24	WNW	17	15	4	.330	1.961	6	9.3	12	WSW	9	.152	21 Feb 68	1.5	168.1	-11.7	8	54	19	1.00
1 Jan 67	[illegible]-2400	12.8	24	WNW	22	19	7	.406	3.510	9	11.8	36	NNW	-4	.254	3 Jan 67	2.0	178.5	-16.3	2	11	[illegible]	1.[illegible]
[illegible] Jan 67	1200-1200	12.2	24	WNW	25	14	-6	.559	5.392	10	13.0	70	NW	10	.483	6 Jan 67	2.0	131.8	- [illegible]	1	24	50	1.[illegible]
[illegible] Dec 66	1400-0700	8.8	14	SE	14	10	19	2.770	1.680	1	--	--	--	15	1.651	7 Dec 66	2.0	104.8	- 5.5	1	12	--	--
1 Feb 67[1]	0300-2400	16.0	24	WNW	30	24	8	.889	7.780	9	11.8	36	NNW	5	.483	14 Feb 67	2.0	174.2	-11.8	8	204	12	1.[illegible]
2 Mar 68[2]	0100-2400	10.6	24	NW	18	13	8	.127	4.040	9	16.0	60	NNW	-7	.152	5 Mar 68	2.5	235.4	-26.8	7	114	--	--
1 Jan 67[3]	0800-2400	12.3	24	WNW	22	19	4	.406	3.510	9	17.0	59	NNW	2	.305	4 Jan 67	3.0	178.8	--	--	24	76	1.[illegible]
Average		12.5	21		21	17	9	.723	3.833	9	12.4			9	.448		1.7	170.8	-10.8	6	84	37	1.03
INITIAL HARD SLAB--3 DAYS OLD OR YOUNGER																						
2 Feb 68	[illegible]-2400	11.8	4	WNW	30	--	6	0.000	1.650	0	6.5	19	NNW	6	0.025	1 Feb 68	1.5	200.8	-18.1	12	350	17	[illegible]
[illegible] Mar 68[2]	[illegible]-2400	15.[illegible]	24	WNW	34	22	-7	.152	[illegible].240	61	15.4	36	NNW	-7	.203	5 Mar 68	2.0	[illegible]	-[illegible]	[illegible]	87	--	--
4 Feb 68[3]	[illegible]-2400	18.4	24	WNW	34	29	14	.152	12.591	83	13.5	60	NW	6	1.372	1[illegible] Feb 67	3.0	49.6	-13.4	19	217	[illegible]	1.[illegible]
Average		14.6	18		29	26	4	.101	8.831	72	11.8			2	.466		2.8	89.2	-17.1	16	467	17	[illegible]
PERSISTENT SOFT SNOW																						
[illegible] Feb 68	[illegible]-[illegible]	12.[illegible]	9	WNW	24	13	16	0.110	2.460	1	11.8	36	NW	14	1.219	[illegible] Feb 68	1.5	[illegible]	- [illegible]	[illegible]	[illegible]	[illegible]	2
4 Dec 66[1]	[illegible]-2400	6.1	24	W	13	8	24	.330	3.800	2	5.8	156	W	7	1.295	1[illegible] Dec 66	4.0	122.2	- 8.8	2	4	[illegible]	[illegible]
[illegible] Feb 68[2]	[illegible]-[illegible]	9.2	6	S	14	12	22	.000	.200	1	7.4	144	S	3	3.581	13 Feb 68	5.0	10.7	- [illegible]	2	[illegible]	1	[illegible].2
Average		9.1	16		14	11	20	.470	3.420	1	8.3			10	2.137		3.5	[illegible]	- 7.[illegible]	[illegible]	[illegible]	[illegible]	.02

[1] Snow crystals [illegible] for good drift ratio.
[2] Setting of hard [illegible] soft slab is arbitrary [illegible] on winds and temperature.
[3] Sample was taken [illegible] weather [illegible].
[illegible] [illegible] pit was dug at 24 hours for lack of more specific data.

also a tendency for air temperatures following the deposition of initial hard slab to be lower than for the other two types of snow. In spite of the averages, there were a few examples of subzero Fahrenheit temperatures during and following the deposition of typical aged snow. In general, however, the case for low temperatures during hard slab formation is reasonably well substantiated by our data.

Another parameter that seems to distinguish periods of initial hard slab deposition is the drift ratio. In our case, this is the water equivalent of the snow layer in the avalanche paths divided by the water equivalent of the precipitation (in Q-12 Park) that fell during the deposition period. Low ratios indicate little wind deposition; high ones indicate heavy wind deposition. The drift ratio during periods of hard slab deposition averaged 8 times that during the deposition of typical snow, and 50 times that during deposition of persistent soft snow. Much of the scatter in the drift ratios is probably due to inaccurate dating of the deposition. When snow stakes were read only once or twice per week, the age of many layers had to be determined somewhat arbitrarily. An accurate evaluation of the drift ratio will have to await more detailed field data.

From our limited sample, initial hard slab appears to require high winds, low temperatures, and a high drift ratio. The two layers of typical aged snow at 1 day and 245.5 kg m^{-3} and at 2 days and 274.2 kg m^{-3} (fig. 2; table 6) illustrate this point. In both cases winds were only slightly below the average for initial hard slab, but the drift ratios were very low and in one case air temperature was quite high. As a result, densities were just on the border between typical aged snow and initial hard slab.

The two samples of older snow measured on December 13, 1966 were 7 and 8 days old, yet they had the density, hardness, and strength of snow less than half that age (see Appendix). This snow was deposited by a large storm that produced 1.24 inches of water in the 24 hours, and 1.74 inches in the 48 hours following noon on December 5. Winds were light during and following the storm; two-thirds of the hourly winds in the post-deposition period were below 10 m.p.h. and none above 18 m.p.h. Temperatures averaged 22° F. during the storm, dropped below 0° F. afterward, remained 0° to 10° F. for 1.5 days, then increased with daytime temperature reaching the mid-20's for the remainder of the period.

The light winds during and after the storm allowed the snow to fall with little or no breakage. After the storm, cold temperatures slowed metamorphism and the light winds were not enough to cause the snow to drift. The slight warming trend toward the end of the period apparently did not reduce the cold content of the pack enough to permit rapid metamorphism before the samples were taken.

Our best example of the influence of weather conditions on snow properties was recorded in early February 1968. During the 23 hours preceding 0900 hours on February 1, winds averaged 7.6 m.p.h. with 24 m.p.h. for the windiest hour and 15.5 m.p.h. for the maximum 6-hour period. The 14 cm of deposition had 4.5 times the water equivalent of the precipitation. It was called typical aged snow on the basis of the age-density relation, although its density approached the upper limit and its ram number and tensile strength were three times the average for this type snow. At about 0900 hours on February 1, the wind increased and precipitation stopped. For the next 5 hours, winds averaged 21.8 m.p.h. with a maximum hour of 30 m.p.h. The 16 cm of deposition was all drift snow. In spite of being 6 to 8 hours younger, this snow was appreciably denser, harder, and stronger than the layer just below (see Appendix). Wind and the accompanying drift snow seem to be the major factors contributing to this change in physical properties, although temperatures did drop slightly.

The 4-cm layer of soft snow at 462-cm height in the pit of February 12, 1967 (see Appendix) is another example of a change in snow stratigraphy reflecting weather conditions during deposition. Although we cannot be sure of the dating, it seems likely this layer was deposited between 1800 hours on February 6 and 1200 hours on February 7. During this time, 0.25 inch (0.635 cm) of water was added to the pack by precipitation; air temperature averaged about 3° F., the winds averaged 11 m.p.h., and the drift ratio was 1.7. The 30-cm layer of tough snow just above the thin, soft layer was probably deposited on February 9, 1967. During this 24-hour period, there was 0.06 inch (0.1524 cm) of precipitation; temperatures averaged 13° F. and winds 18.6 m.p.h. The drift ratio was 82.6. This dense, hard layer was almost completely drift snow put in by high winds (maximum

6-hour period averaged 29 m.p.h.). Temperatures were moderate (13° F.) during deposition and a little colder (6.4° F.) during the 60-hour post-deposition period. The switch from moderate precipitation with little or no wind to very light precipitation and strong winds seems the most likely reason for this dramatic change in snow properties. Temperatures did not follow the expected pattern.

The 4-cm layer of soft, weak snow, sandwiched between two hard, tough layers was obvious when the pit wall was examined. It also showed up in the tensile strength, density, and ram resistance data. Because such weak layers frequently form the basal shear plane of avalanches, it is important to locate them in the pack. When weak layers are only a centimeter or less in thickness, however, it is very difficult to detect them with conventional field techniques. Noel C. Gardner (personal communication), working in British Columbia, Canada, found that weak layers appeared brighter than others when a strong light was put behind a vertical section of snow at night.

Some field men have long suspected that extremely high winds (50-70 m.p.h.) do not form hard slab; others say such winds produce "very hard" slab but few slab avalanches. Our data give no information on a possible upper wind threshold for hard-slab formation.

Summary and Conclusions

The average age of the snow studied was 5 days, and most of it did not exceed 14 days. Density varied from 40 to 450 kg m^{-3} with the latter value measured in 3-day-old snow 50-60 cm below the surface. Samples taken parallel and perpendicular to the layering within a layer showed no significant density differences. Three types of snow were distinguished on the basis of the density-age relation: high-density young snow—called initial hard slab; low-density old snow—called persistent soft snow; the remainder—called typical aged snow. The last two types would be called soft slab by the field man. There is little doubt these three types form a continuous array rather than three discrete populations.

Most of the avalanches that ran on days when initial hard slab was observed in the study pits were of the hard slab variety. Soft-slab avalanches predominated on days when typical aged or persistent soft snow were found in the pits. For the entire 3 years of study, initial hard slab appeared in 15 percent of the pits. During the 18-year period 1950-68, however, hard-slab avalanches accounted for about 30 percent of the total avalanches on nearby paths. Apparently many of the hard-slab avalanches in this part of Colorado involved old snow.

Tensile strength as measured by the centrifugal or spin tester varied over three orders of magnitude. Although strength generally increased with density, there was a tendency for the younger snows to be weaker than older snows of the same density.

Shear strength was measured by the torque vane and also by a small open shear frame. The relation between tensile strength and shear strength as measured by the torque vane was about 1:1. Shear strength as measured by the frame was lower than any of the other strength indexes.

The relation between tensile strength and shear strength as measured with the shear frame varied with strength and age. The ratio of tensile to shear frame strength was about six to one for strong snow layers, but decreased to less than two to one for weak snow. When age was considered, the six-to-one ratio was characteristic of snow 10 to 14 days old, while the lower ratio applied to young snow.

The logarithm of ram resistance showed a positive linear correlation with density that was not greatly different from the correlations found for polar snow and for seasonal snow cover of several other Western States. Snow from wind-exposed alpine areas had a higher ram resistance for a given density than snow from a nearby opening in the trees.

The coefficient of air permeability was between 10 and 30 cm^2 sec^{-1} (cm of water)$^{-1}$ for 70 percent of the samples. This is about one order of magnitude lower than expected. Permeability was found to vary with flow rate and pressure differential when flow rates were low. The ratio of virtual porosity to actual porosity averaged 1.062 for snow no more than 14 days old. This confirms previous data for "average metamorphosed" snow. The averages for initial hard slab, typical aged snow, and persistent soft snow were 1.08, 1.03, and 1.02, respectively. Although on the average this ratio distinguishes initial hard slab, the difficulty in making the measurement and the scatter of individual readings make it useless as a field guide.

Air permeability helps explain some of the scatter in the strength-density relation. For snow of a given density, there appears to be some intermediate or "optimum" permeability above and below which strength decreases. Furthermore, this optimum permeability decreases with an increase in density. To the extent permeability is an index of texture, this means strength is a function of density and texture.

Initial hard slab was correlated with moderate to high windspeed, cold temperatures, and the presence of wind-transported snow.

No good way was discovered to distinguish between hard slab that was formed in just a few days (initial hard slab) and that which formed over a longer period of time. Even though we have shown that younger snow has lower strength for a given density than older snow, this is not well enough documented to be diagnostic.

The relatively numerous hard-slab avalanches reported from the high alpine area west of Denver, Colorado, are probably due to several things. Undoubtedly the initial hard slab described in this report is one factor. Another important factor, however, is that in this region of relatively low snowfall both natural and artificial triggers often release hard older layers.

This study indicated the need for fast and simple **in situ** methods for measuring the mechanical and physical properties of low-density fresh snow. One thing that would be especially useful would be a lightweight rammsonde, and another would be a better classification scheme for snow on the ground.

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APPENDIX

Summary of Physical and Mechanical Properties of Alpine Snow--Mostly Less Than 2 Weeks of Age

Date	Location	Grain size and type[1]	Temperature	Density	Ram no	Age	STRENGTH INDICES: Torque vane	Shear frame	Tensile (spin)	Average tensile	Average density	Height above datum	Density	Voros ct	Virtual porosity	N/t	'a'[2]	Permeability	Average permeability	Remarks
		mm	°C	kg m⁻³	kg	days	- -	gf cm⁻²	- -	- -	kg m⁻³	cm	kg m⁻³					cm/sec (cm water)		
1965																				
28-29 Jan.	LIFT GULLY											171	Snow surface							
		a	-12.0			< 1		6.1				157								
		a	-13.0			< 1						145		121.4	0.868					
		0.5 b	-14.0			2						118		239.0	739	0.758	1.0252	3 5	66 56*	*Permeabilities for this run may be poor because samples stayed in tubes overnight.
		<.5 b	-14.0			3		29 4				83								
												75		208.8	750	795	1.0605	3 0	42 19	
		1.0 d	-10.4	197.6		--		45.4				28		197.6	784	.867	1 1055	17 2	156 00	
												-5*		315.6	655	.714	1.0905	8 0	117 91	*Below basal failure plane of avalanche
3-4 Feb.	LIFT GULLY											230	Snow surface							
		1.0 d	-6.2	340.6	9	≤ 6		60.5				220		340.6	628	682	1.0860	2 4	21.20	Tests taken just above fracture line of hard slab avalanche
		<.5 d	-9.9	330.2	15	≤ 6						200		330.2	.630	.659	1.0460	2.4	25 85	
		.5 d	-11.5	316.8	40	≤ 6	99.2	70.8				180		216.8	.654	.692	1.0581	2 0	24 45	
		<.5 d	-11.3	336.0	35	≤ 6						160		336.0	634	.679	1.0710	1 8	20 00	
		<.5 d	-11.0	316.2	44	6	252.0	82.4				140		316.2	655	.709	1 0886	1.5	16 19	
		<.5 d	-8.5	--	9	6	102.0	114.0				115								
		<.5 d	-8.2	322.4	9	6						110		322.4	649	.711	1.0955	0.5	3.98	
		<.5 d	-6.0	308.6	35	--						85		308.6	.663	.704	1 0618	1 4	17 91	
						--	266 0	125.5				80								Basal failure plane of avalanche was at 60 cm height
		3.0 e	-2.8	--	6	--	28.3	86.5				55								
		3.0 e	-2.7	332.4	6	--						50		332.4	638				65.95	
		3.0 e	-2.1	290.2	6	--						20		290.2	.684				114 90	
15-16 Mar.	URAD #5											343	Snow surface							Tests taken in snow uphill from fracture line of a soft slab avalanche that ran 24 hours previously.
		.5 b	-9.7		1	<14						313		229.8	.749	.792	1.0574	3.0	49.06	58 44
														216.6	.763	.792	1.0380	3.0	67.82	
		.5 b	-9.7		2	<14	28.3	7.6				290		241.8	.736	.808	1.0978	2.5	40.83	55.88
														161.0	.823	.857	1.0413	2.5	70.94	
		.5 b	-9.2		2	<14						262		222.2	.758	.772	1.0185	2.0	60.68	50.05
														241.2	.737	.772	1.0475	2.0	39.42	
		.5 b	-8.8		10	<14	34.0	21.5				255								
		---	--		3		146.0					210		338.6	.630	692	1.0984	15.0	102 48	102 77 Basal failure plane of avalanche was at 230 cm
														337.0	.632	.692	1.0949	15.0	103.06	

[1] Snow types are those given in International Association of Hydrology. Commission on Snow and Ice, 1954.
[2] See equations 2 and 3, p. 20 and 21.

Summary of Physical and Mechanical Properties of Alpine Snow--Mostly Less Than 2 Weeks of Age--continued

Date	Location	Grain size and type[1]	Temperature	Density	Ram no.	Age	STRENGTH INDICES: Torque vane	STRENGTH INDICES: shear frame	STRENGTH INDICES: Tensile (spin)	STRENGTH INDICES: verage tensile	Average density	Height above datum	Density	Porosity n	Virtual porosity N	n/n	"a"[2]	Interchangeability	Average pen. resistance	Remarks
		mm	°C	kg m^{-3}	kg	days	- -	gf cm^{-2}	- -	- -	kg m^{-3}	cm	kg m^{-3}						cm sec (cm water)	
5 Mar. '66	BELAY POST 4											50 Snow surface								
		--	-20.9		25	2	183.2			306.7	355.4	30								Initial hard slab (Average of 5 samples)
		--	-16.8		5	2½	34.0			116.2	235.4	12								Top layer of snow was harder and tougher than older layer below (average ...)
1966-1967																				
7 Dec. '66	BELAY POST 4											161 Snow surface								Fresh snow very soft slab
		b	-6.2	118.2 121.0	1	1	5.7	3.8	4.2 8.0	6.1	119.6	145								
		0.5 b	-5.5	106.6 103.2	1	2		6.4	22.4 20.6	21.5	104.9	125								
13 Dec. '66	BELAY POST 5											102 Snow surface								Snow soft Density tubes dropped out of sight
		2.0 a	-8.4		1							100								
		.4 b	-8.8		2	7						84	170.2	.815	.675	.8280	3.0	--	136.82	
													169.4	.816	.727	.8909	3.0	136.82		
		.4 b	-8.8	162.2 164.0	2	7	6.7	5.8	4.2	4.2	162.2	81								Persistent soft snow
		.4 b	-7.2		2	7						76	174.6	.809	.800	.9838	5.0	384.05	313.86	
													180.4	.804	.820	1.0199	8.0	243.67		
		.4 d	-5.4	172.6 162.8	2	8	8.0	9.4	46.4 51.9	49.2	167.7	65								Persistent soft snow
		2.0 de	--	301.2	3	--						8								
3 Jan. '67	BELAY POST 4											175 Snow surface								
		.7 bd	-16.3	176.4 174.6	2	2	11.4	8.4	18.2 6.9	12.5	175.5	163	214.4 221.6	.767 .758	.813 .787	1.0500 1.0380	1.8 1.6	20.08 13.76	16.92	
4 Jan. '67	BELAY POST 4											230 Snow surface								Same snow as that tested 3 Jan 67
	Pit 2	--	--	173.2					32.0			200								
		--	--	147.0	--	3	39.0	13.6	28.4	21.5	136.0									
		--	--	128.0					14.5											
		--	--	95.6					11.2			190	204.6	.777	.775	.9970	1.0	14.52	26.00	
													186.4	.797	.800	1.0040	1.2	37.48		
	Pit 1											42 Snow surface								Snow at 32 cm height less than 18 hours old
		1.5 a	-7.8	36.2 33.4	--	½			1.0 1.4	1.2	35.8	32								
		.5 b	-12.5			3						5	154.0	.832	.831	1.0000	1.7	22.89	25.28	
													146.4	.873	.885	1.0140	1.7	27.68		
6 Jan. '67	N. CHUTE OF CLIFFS											97 Snow surface								
		bd	-9.0	142.2 147.4	2	2	18.5	15.1	27.9 39.3	33.6	134.8	66	133.2 135.6	.855 .852	.873 .879	1.0211 1.0317	2.4 2.0	50.01 50.80	50.40	
		bd	-7.7	144.2 149.4	3	4	24.2	--	9.5 12.2	10.9	153.0	45	214.6 198.0	.766 .784	.821 .859	1.0718 1.0957	2.2 2.5	20.56 26.37	23.46	

Date	Location	Hardness	Wetness	Grain form	Grain size (mm)	Layer thickness (cm)	Compressive strength (kg/cm²)			Height above ground (cm)	Density (gm/cm³)	Porosity n	Pore volume per gram N	Sphericity n	"a"²	Pore-size variability	Remarks
							Top of layer	Bottom of layer	Density (gm/cm³)	Average strength	Average density								
15 Jan. '67	BELAY POST 4	.6 b	-8.5	1a1,2a	2	2					202 200	Snow surface							
		.6 b	-9.8			8	77.0				192		727 713	733 736	1.0083 1.0323	2.9 3.7	20.04 18.36	19.20	Probably extends into d layer too
		3 d	-10.2	1a,2a,3	14	5	262.0	105.5	179.8* --	179.8*	1.1	156							
		2 d	-10.4	1a,2a,3	19	10	150.9	83.0	358.9 486.3	382.6	1.4	168		650 662	.629 .705	1.0446 1.0650	1.5 2.2	12.79 12.76	12.74	
31 Jan. '67	BELAY POST 4	.7 bd	-9.0	1a,2a,3	2	4½	51.3	38.2	161.6 -- --	161.6	1.4	301 277	Snow surface	.767 .754	777 860	1.0130 1.0610	0.6 3.1	17.30 27.85	22.58	
		.7 bd	-10.4		5	8						250		782 787	800 824	1.0230 1.0470	2.2 2.7	25.40 29.45	27.42	
		.7 bd	-10.4	1a,2a,3	5	8	53.2	54.5	255.1 -- 246.6	250.8	1.4	246							
		.5 d	-10.2	1a,2a,3	48	13	697.5	120.0	944.9 859.6 682.9	829.1	1.4	218		.627 .651	.648 .6955	1.1132 1.1	8.6 1.7	29.82 25.85	27.55	
1 Feb. '67	BELAY POST 3								--			465	Snow surface							
		.7 bd	-10.4	1a,2a,3	4	4½	59.8	27.6	124.3 143.0	133.6	1.4	435		770 766	824 794	1.0701 1.0366	3.1 3.3	34.55 29.45	33.10	
		.7 bd	-12.6	1a,2a,3	7	6	115.4	45.6	185.0 263.4 126.8	215.1	1.7	395		755 747	.760 778	1.0466 1.0415	1.6 2.4	28.99 24.04	26.52	
		.4 d	-13.0	1a,2a,3	98	13	1835.5	--	858.8* 1396.3 1547.9	1267.7	1.4	330		575 .576	639 .630	1.1113 1.0938	0.9 1.1	10.01 12.62	11.32	*This reading may be ba

Summary of Physical and Mechanical Properties of Alpine Snow--Mostly Less Than 2 Weeks of Age--continued

Date	Location	Grain size and type[1]	Temperature	Density	Ram no.	Age	STRENGTH INDICES: Torque vane	Shear frame	Tensile (spin)	Average tensile	Average density	Height above datum	Density	Porosity n	Virtual porosity N	S/n	"a"[2]	Permeability	Average permeability	Remarks
		mm	C	kg m^{-3}	kg	days	- -	gr cm^{-3}	- -	- -	kg m^{-3}	cm	kg m^{-3}					m sec (cm water)		
12 Feb. '67	BELAY POST 3											553	Snow surface							
		.5 b	-11.7	192.3 203.0	3	1½	42.8	17.7	51.3 57.4	54.4	190.1	541	215.0 222.6	.766 .757	.806 .800	1.0522 1.0568	1.3 1.6	19 77 17 40	18 58	
		.5 b	-11.8	286.3 263.4	8	2	111.0	30.4	151.8 55.4	103.6	274.9	521	245.2 246.8	.744 .731	.769 .748	1.0336 1.0233	1.8 1.6	24 27 18 90	21 58	Not quite initial hard slab
		.5 d	-12.6		95	2½						498	449.5 448.6	.509 .510	.568 .510	1.1159 1.1176	1.4 1.4	7.38 7 11	7 24	
		.5 d	-12.4	445.6 447.6	80	3	1112.0	186.6	999.6 634.9	817.0	446.6	488								Initial hard slab.
		.5 d	-12.8		65	5						478	390.2 384.2	.568 .581	.597 .611	1.0511 1.0516	1.1 1.1	11.36 10.71	11 03	
		.8 d	-13.0	277.4 274.2 268.0	28	6	--	49.2	-- 388.9 358.8	373.8	270.1	465								Narrow soft layer
		.5 d	-13.2	434.8 424.0	85	8	-- -	169.2	909.7 1711.8	1311.7	429.4	431	413.2 434.6	.550 .526	.559 .593	1.0164 1.1274	1.4 1.7	37.94 11.00	24 47	Initial hard slab.
1967-1968 7-8 Dec. '67	BELAY POST 4											218	Snow surface							Above fracture line of hard slab avalanche.
		.7 bd	-13.4	206.4 240.5 239.4 222.0	3	3	24.7	4.5*	-- -- 50.3 5.7*	50.3	239.4	209	210.0 217.4 213.8 215.0	.771 .763 .767 .766	-- -- -- .796	-- -- -- 1.0392	-- -- -- 1.2	-- -- 21.32 18.35	19.84	*Bad readings.
		.4 d	-11.7	411.0 396.5 397.6	126	--	716.7	-	-- 890.2 664.8	777.5	397.2	176	407.2 403.0	.556 .554	.609 .608	1.0953 1.0975	1.6 2.8	10.95 10.05	10.50	
		.4 d	-6.3	364.4 362.4	44	--	755.1	116.3	561.9 470.7	516.3	363.4	95	353.2 361.2	.615 .606	.634 .628	1.0309 1.0363	2.5 2.2	24.81 19.67	22.24	
		1.2 d --	-3.6	290.6 257.2	15	--	--	--	226.5 172.4	199.4	286.1	50	309.0 [illegible]	.663 .648	.732 .806	1.1041 1.2438	7.6 12.2	42.08 46.68	44.38	Basal shear plane of avalanche at 42 cm
		-	-2.3	463.0	18	--	58.9	34.8	279.3	279.3	353.0	20	338.6	.634	.667	1.0520	10.0	48.43	48.43	
21 Dec. '67	LIFT GULLY											184	Snow surface							Sonic boom test--above fracture line of soft slab avalanche
		--	-22.7	304.0 294.2 304.0	5	≤1	--		- -- --	--	307.2	165								
		--	-22.4	327.4 [illegible] [illegible]	2	≤1	--	--	12.9 5.1* 32.4	32.4	177.2	154								*Bad reading - not used in average
		--	-21.9	--				8.7				145								Basal shear plane of avalanche at 142 cm

Date	Location	Grain size and type[1]	Temperature	Density	Ram no.	Age	STRENGTH INDICES: Torque vane	Shear frame	Tensile (spin)	Average tensile	Average density	Height above datum	Density	Porosity n	Virtual porosity N	N/n	"a"[2]	Permeability	Average permeability	Remarks
		mm	°C	kg m	kg	days	- -	gf cm⁻²	- -	- -	kg m	cm	kg m					m sec⁻¹ (cm water)		
17-19 Jan. '68	STATION 3											436	Snow surface							Deep pit - midwinter
		.5 b	-10.9	183.2 183.6	2	5	31.3	14.8	22.8 97.3	60.0	183.4	431								
		.5 d	-13.7	313.6 314.0	52	14	262.2	53.4	407.3 407.8	407.6	413.6	405	333.2 333.0	.636 .637	.704 .780	1 1069 1.2245	1.8 1.8	16 77 17 30	17 04	
		.5 d	-13.2	284.0 285.2	28	22	412.1	94.3	336.4 439.8	338.1	284.6	380	293.2 294.2	.680 .679	.733 .741	1.0780 1 0913	3 0 3.2	29 13 26.98	28 06	
		.5 d	-12.0	316.0 313.8	32	22	639.2	141.4	661.2 803.2	732.2	314.9	345	314.6 321.2	.656 .650	.698 .695	1.0640 1.0692	2.0 2.3	27 13 28.30	27 72	
		.5 d	-10.2	409.8 413.8	140	26	892.8	184.0	2102.9 1501.5	1802.2	411.3	295	416.0 415.8	.544 .546	.557 .567	1.0054 1.0385	1.6 1.6	15 14 15.29	15 22	
		.5 d	-10.7	356.0* 384.0 409.4 402.8*	88	32	-	-	571.7* 694.0 1186.6 1974.4*	940.3	390.7	260	383.0 385.6	.583 .578	.597 .576	1.0240 .9862	2.6 1.6	28.46 22.10	25.28	*These densities were taken perpendicular to fall line and not parallel to it as were all other tensile samples
		.5 d	-9.7	433.4* 390.2 426.4 436.2*	82	--	--	--	1657.7* 875.4 -- --	875.4	396.1	220	421.8 404.6	.529 .559	.565 .588	1.0681 1.0519	2.6 3.2	27.53 25.80	26.66	
		.5 d	-7.6	397.0 401.3	62	--		-	830.7 --	830.7	397.0	170	417.0 415.0	.547 .558	.585 .622	1.0695 1.1147	4 1 4.9	30 63 32.73	31 68	
		-- e	-4.2	459.6 458.6	108	--	-	--	509.6 1028.8	769.2	457.1	111	473.2 469.8	.484 .487	.540 .557	1.1157 1.1437	6 4 8.9	37 64 40 17	38.90	
		1.5 e	-2.7	414.8 416.6	70	--	249.6	220.1	693 6 696.6	695.1	415.7	80	451.2 452.2	.508 .507	.527 .530	1.0375 1.0454	5.9 6.0	45 42 42.12	43 77	
		1.5 e	-1.4	491.0 495.2	142	--	665.7	351.0	1599.0 --	1599.0	491.0	30	498.0 499.8	.457 .455	.444 .456	.9724 1.0035	3 6 3.9	29 04 30 42	29 73	
2 Feb. '68	STATION 3 LINE A STAKE 7											45	Snow surface							
		.5 b	-18.1	288.2 270.0 301.0 288.6	22	1	258.2	79.9	172.4 -- 160.5 225.4	186.1	290.6	30	280.3 288.7	.695 .686	.711 .733	1 0230 1.0685	1.0 1.6	16.21 14.62	15 42	Initial hard slab.
		.5 b	-16.0	224.2 230.6 207.4	15	1½	121.4	53.4	119 6 180.1 162.0	153.9	220.7	12	244.0 239.8 236.4	.734 .738 .743	.729 .760 .766	.9932 1.0298 1 0310	1.2 1.3 1 8	21.06 21 06 30 04	24 05	
20 Feb. '68	STATION 3 LINE B STAKE 6											79	Snow surface							
		.7 bd	-7.2	250.6 240.4	8	1	95.0	38.6	143.1 94.9	119.0	245.5	65	267.8 266.4	.708 .710	.679 .721	.9590 1.0155	1.7 1.6	14.09 15 65	14.87	Not quite initial hard slab
		1.0 db	-8.1	164.8 159.8	3	4	57.0	21.6	76.0 91.3	83.6	162.3	40								
		.6 d	-9.8	257.0 237.0	10	19	72.2	40.2	250.0 --	250.0	257.0	20	231.0 229.4	.748 .750	.763 .818	1.0201 1.0907	2.1 2.3	27.09 29 46	28.28	

Summary of Physical and Mechanical Properties of Alpine Snow--Mostly Less Than 2 Weeks of Age--continued

Date	Location	Grain size and type[1]	Temperature	Density	Ram no.	Age	STRENGTH INDICES: Torque vane	STRENGTH INDICES: Shear frame	STRENGTH INDICES: Tensile (spin)	STRENGTH INDICES: Average tensile	Average density	Height above datum	Density	Porosity n	Virtual porosity N	N/n	"a"[2]	Permeability	Average permeability	Remarks
		mm	°C	kg m⁻³	kg	days	- -	gf cm⁻²	- -	- -	kg m⁻³	cm	kg m⁻³					sq. cm	cm water	
23 Feb. '68	STATION 4 LINE C STAKE 5											161	Snow surface							
		1.0 b	-7.8	67.6 73.0	2	1½	--	3.2	4.8 4.4	4.6	70.3	133	84.8 80.6	.904 .909	.913 .943	1.0100 1.0374	3 5 5 0	88 19 116.24	103 22	Persistent split snow
		.5 bd	-7.2	183.8 177.8	3	4	5.7*	27.3	75.6 71.0	73.3	180.8	95	193.6 193.6	.786 .788	.855 .839	1.0850 1.0647	5 0 4.3	51 31 58 92	55 12	*Reading suspect snow too weak to give good reading
		.2 d	-7.8	310.6 314.4	33	5	201.4	86.3	696.8 568.2	632.5	312.5	60	312.8 315.6	.659 .655	.708 .680	1.0744 1.0382	2.0 1.9	21.66 20 34	21.00	
		.3 d	-8.9	253.0 247.4	26	11	123.5	71.8	273.2 525.2	399.2	248.2	20	243.8 253.6	.734 .723	.756 .800	1.0300 1.1065	3.5 3.8	47 70 33.69	40 70	
29-30 Apr '68	STATION 3 LINE B STAKE 2											601	Snow surface							
		1.5 bd	-3.6	191.6 190.6	1	4	53.2	3.6	118.2 194.2	156.2	210.6	585	208.2 210.6	.773 .770	.818 .795	1.0582 1.0325	3.6 2.4	37.61 29.58	33 60	Late season deep pit
		.5 bd	-5.7	334.2 336.6	40	--	283.1	68.6	749.7 755.1	752.4	335.4	550	357.0 364.8	.611 .602	.623 .663	1.0196 1.1013	3 4 4 0	19 67 25 83	22 75	
		.8 d	-6.5	371.2 358.4	65	--	672.0	142.0	1350.2 1160.6	1255.4	363.8	480	366.2 369.4	.601 .598	.644 .674	1.0716 1.1271	3.1 3 2	23.77 24 84	24 30	
		.3 d	-5.2	260.0 267.3	225	--	1920.0*	272.6	-- 2507.3	2507.3	267.4	340								*Reading was in excess of this but can't get more snow

Martinelli, M., Jr.
1971. Physical properties of alpine snow as related to weather and avalanche conditions. USDA Forest Serv. Res. Pap. RM-64, 35 p., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

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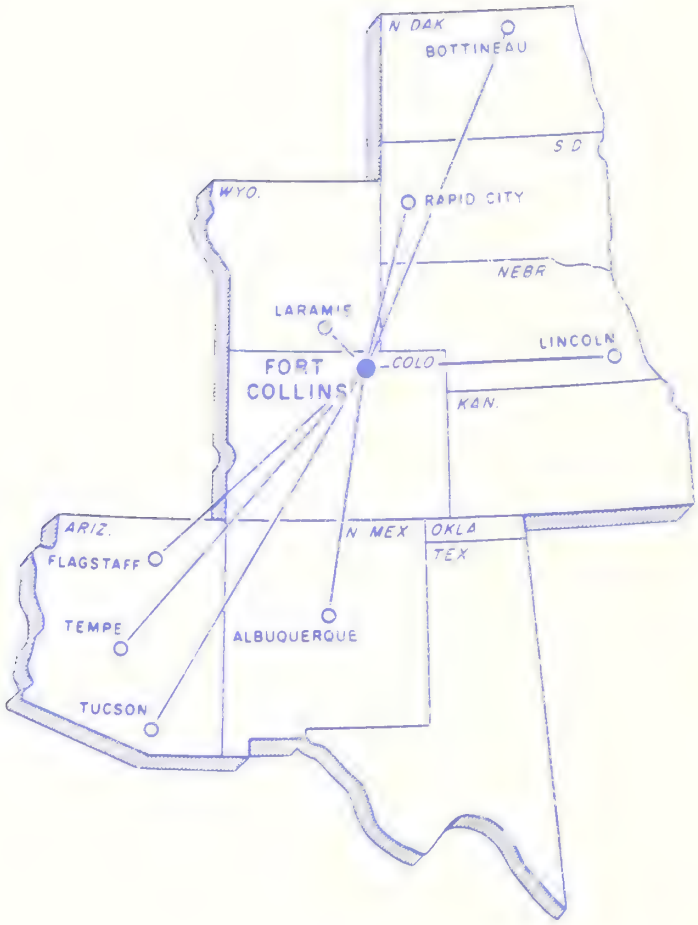
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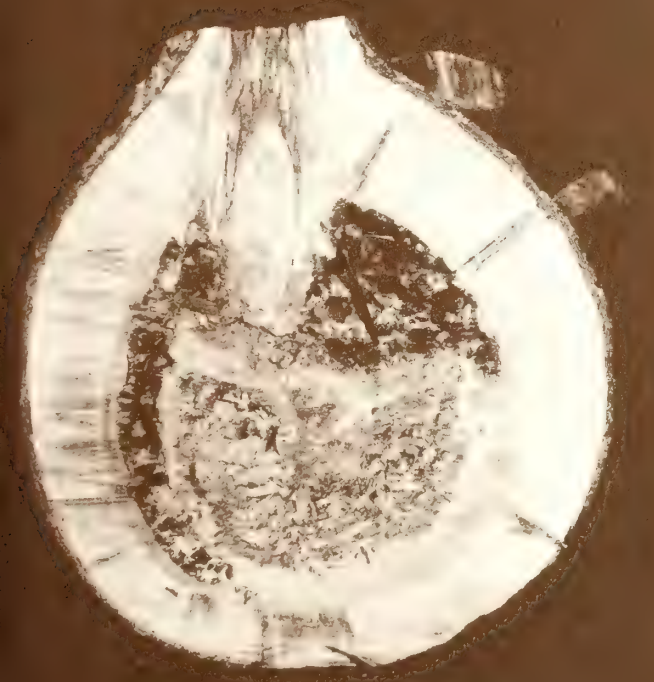

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decay of ponderosa pine sawtimber in the black hills

By Thomas E. Hinds

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Abstract

A defect study of 1,725 logs cut from 498 trees provided the basis for determining the relationships between tree age, volume, and defect. Red rot was responsible for 8.6 percent, brown rots 7.3 percent, and other defects 3.3 percent of the total 19.2 percent defect. Red rot, found in 68 percent of all trees, was the most important cause of defect.

Key words: Polyporus anceps Pk., Pinus ponderosa, lumber quality, tree volume estimates.

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Decay of Ponderosa Pine Sawtimber in the Black Hills[1]

by

Thomas E. Hinds, Plant Pathologist

Rocky Mountain Forest and Range Experiment Station[2]

[1]From a thesis submitted in partial fulfillment of the requirements for a M. S. degree at Colorado State University.

[2]Central headquarters maintained at Fort Collins, in cooperation with Colorado State University.

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Decay of Ponderosa Pine Sawtimber in the Black Hills

Thomas E. Hinds

Introduction

Commercial forest lands in the Black Hills of western South Dakota cover approximately 1.3 million acres and contain 3.3 billion board feet of sawtimber (Choate and Spencer 1969). Ponderosa pine (Pinus ponderosa Laws.) makes up 95 percent of the total volume. The net annual growth of pine sawtimber in the Black Hills in 1969 was estimated to be 86.5 million board feet, whereas the annual cut amounted to 53.2 million board feet (International 1/4-inch log rule). The lumber industry in the Black Hills is threatened less by shortages in raw material than by competition from other construction materials for markets formerly served by common grades of lumber (Mueller and Kovner 1967). Accordingly, the industry continually requires a general tightening up in all expenditures and practices. Errors in estimating volume and quality of timber, or logging or milling costs and lumber yields, can be serious in the lumber industry. Many of these errors result from failure to identify and make proper allowances for defect.

Defect has been recognized as a serious problem in Black Hills ponderosa pine for many years. According to Hoffman and Krueger (1949), the timber has always had a high cull factor (15 to 35 percent). It has been reported that losses from red rot, caused by Polyporus anceps Pk., in old-growth stands amounted to about 25 percent of the volume cut (Andrews and Gill 1941). The only mensurational study of red rot in the Black Hills dealt with factors affecting rot incidence in immature stands up to 140 years of age, however, and did not provide any data on volume losses in sawtimber (Andrews and Gill 1941).

In 1962, a cooperative lumber grade recovery study by the USDA Forest Service and private industry[3] provided an opportunity to determine the volume and significance of red rot and other heart rots in older merchantable-sized trees. One of the secondary objectives of the lumber grade recovery study was to develop improved criteria for identifying the presence and extent of scalable rot defects. More importantly from a pathological standpoint, however, the study enabled us to investigate the relationship of rot to various characteristics of trees, stands, and sites, as well as identify associated decay fungi.

Methods

The decay study was limited to the 498 trees selected for the lumber grade recovery study. These selections were made according to criteria designed to insure a reasonably representative sample of all diameters and log grade classes available in the Black Hills (Mueller and Kovner 1967). The trees were randomly selected, as far as possible, within these classes from trees marked for cutting on sale areas on 5 of the 10 Ranger Districts of the Black Hills National Forest (fig. 1).

The lumber grade recovery study provided stand and tree measurement data for each tree. Stand

[3] *The Ventling-Richtman Sawmill and the Custer Lumber Planing Mill provided the use of their plant facilities. The Buckingham Wood Products Company and the Homestake Mining Company provided men and equipment needed to select and handle the sample trees and logs. Others who assisted include the Western Wood Products Association, and the Forest Products Laboratory and the Western Pine Log Grade Project of the USDA Forest Service.*

Figure 1.--Location of five sale areas from which trees were selected in the Black Hills National Forest in South Dakota.

data included stand age, soil type, aspect, slope gradient, slope position, stand density, and site index. Tree measurement data included crown class, crown density, crown length, stump height, tree height, height to first live and dead branch, height of the clear bole and to the base of the tree crown, tree diameter, and bark retention on dead branch stubs (a reliable indicator of red rot in 60- to 100-year-old trees in the Southwest). After trees were felled, bucked, and scaled, tree and log numbers were painted on each log end, and log length was recorded on a tree measurement form. All merchantable logs (a net scale of one-third or more of the gross log scale) were deposited at the sawmill yard.

Various log dimensions and surface defects were recorded for each log on a standard form, which included u cross-sectional diagram of both log ends. Supplemental data on type, stage, and amount of visible decay on log ends were diagramed on the form. Each log was then rescaled by USDA Forest Service and Western Wood Products Association check scalers. All gross, net, and defect volumes were identified by tree and log number.

Debarked logs suitable for canting were sawed into cants on a circular head rig and passed to a sash gang saw where they were cut into 1-inch boards (fig. 2). Salvable lumber from a few logs too defective for canting was routed directly to the edger. The boards of all logs containing decay that were routed through the sash gang saw were photographed as they were laid out and numbered on a slow-moving transfer chain leading to the edger (fig. 3). A 35 mm. reflex camera with a 28 mm. wide-angle lens was used in conjunction with two strobe lights placed overhead at 45° angles to the long dimension of the boards. The rough green

Figure 2.--Sash gang cutting cants (at rear of saw) into 1-inch boards (foreground).

Figure 3.--Boards of a cant containing red rot laid out for numbering and photographing.

lumber was edged, trimmed, sorted, graded, kiln dried, and finished for other volume comparisons.

Cull logs and segments left in the woods were examined to complete the records on defect. These were cut into 4-foot sections to reveal the extent and type of decay. Fungi from decaying wood were cultured for identification. To aid in the culture identifications, sporophores of decay fungi were collected in the five areas during July 1965. All sporophores and decay cultures were sent to the USDA Forest Disease Laboratory, Laurel, Maryland, for identification.

All merchantable and cull log data from the lumber grade recovery study (Mueller and Kovner 1967) were used in this decay analysis. Since the net volume determined by the Forest Service log scale (Scribner Decimal C rule) was within 1 percent of the total lumber produced (dry finish basis), the Forest Service scale data were used.

Pictures of decayed boards were enlarged to 7 diameters. A plastic scale overlay was made to fit the pictures so that length of decay columns in the boards could be measured. Cubic-foot volume was calculated for each log by Smalian's formula. Rot volume was calculated in the same way, except that where rot ended within a log it was treated as a cone.

Results and Discussion

A total of 1,725 logs was cut from the 498 trees. Rot defect amounted to 15.9 percent and total defect 19.2 percent of the gross board-foot volume (table 1). All white-pocket rot was assumed to be red rot, although laboratory study may reveal that P. anceps is not the only cause of this type of decay. Red rot was responsible for slightly more defect than brown cubical rots (8.6 and 7.3 percent, respectively). The remaining 3.3 percent was attributed to other defects such as cat faces, checks or splits, crotch or fork, crook or sweep, fire scar, lightning scar, and other unclassified injuries. Red rot was present in 68 percent of the trees, whereas brown cubical rots were present in only 36 percent; 27 percent of the trees contained both red rot and brown rot. Red rot amounted to 45 percent of the defect, brown rot 38 percent, and other defects 17 percent.

Defect and Log Position

The incidence of defect by log position is given in table 2 and the volumes involved in table 3.

Butt logs contained 42 percent of the total gross volume and 30 percent of the total defect. Of this butt log defect, red rot was responsible for 4.5 percent, brown rot 16.1 percent, and other defects 9.4 percent. Although the incidence of other defect was higher in the butt log, it did not cause as much volume loss as brown rot. All other logs contained 58 percent of the gross volume and 70 percent of the total defect. Red rot accounted for 40.6 percent of the defect in the upper logs, brown rot 22.3 percent, and other defects 7.1 percent. Red rot is thus the most important defect in the upper, smaller logs, while brown rot is the most important in butt logs (tables 2, 3).

Table 1.--Summary of basic data from the five study areas

Area	Number of trees	Average age	Average d.b.h.	Total tree volume (Scribner Dec. C scale)		Total percent rot	
		Years	Inches	Bd. ft.	Cu. ft.	Bd. ft.	Cu. ft.
Buck Springs	100	182	18.2	31,170	5,778.9	19.0	7.3
Golden West	100	223	18.1	35,670	6,731.2	19.9	9.9
Herbert	100	235	17.9	39,690	7,185.4	20.1	8.7
Higgens Gulch	100	167	18.1	39,360	7,284.9	9.9	5.2
Iron Creek	98	179	18.3	36,560	6,829.0	11.7	5.7
All areas	498	197	18.1	182,450	33,809.4	15.9	7.3

Table 2.--Incidence of defect, by log position

Log position	Logs	Defect incidence		
		Red rot	Brown rot	Other
	No.	- - - - Percent - - - -		
Log 1	498	12.9	21.7	29.5
Log 2	487	26.5	10.1	9.4
Log 3	380	34.7	10.5	7.4
Log 4	238	40.3	9.7	10.5
Log 5	91	33.0	8.8	10.5
Log 6+	31	22.6	3.2	29.0
Total	1,725	26.5	12.3	15.7

Table 3.--Defect volume, by log position

Log position	Gross volume	Defect volume			
		Red rot	Brown rot	Other	Total
	Bd. ft.	- - - - Percent - - - -			
Log 1	76,840	2.0	7.3	4.3	13.6
Log 2	56,370	8.9	6.5	1.5	16.9
Log 3	31,890	16.7	9.0	1.8	27.5
Log 4	13,170	22.2	8.1	4.3	34.6
Log 5	3,050	27.2	6.2	10.2	43.6
Log 6+	1,130	9.7	.9	16.8	27.4
Total	182,450	8.6	7.3	3.3	19.2

Defect and Tree Age

The relationships between defect and tree age, d.b.h., aspect, slope, stocking, site index, crown class, and crown density were tested by multiple regression analysis for individual areas and for all areas combined. The only significant correlation was between defect and tree age (fig. 4). The slopes of the lines in figure 4 were obtained by regressions, with the number of trees in each 20-year age class (the independent variable) as weights.

The relationship between red rot defect and tree age was expected to be similar to that found in the Southwest (Lightle and Andrews 1968), where red

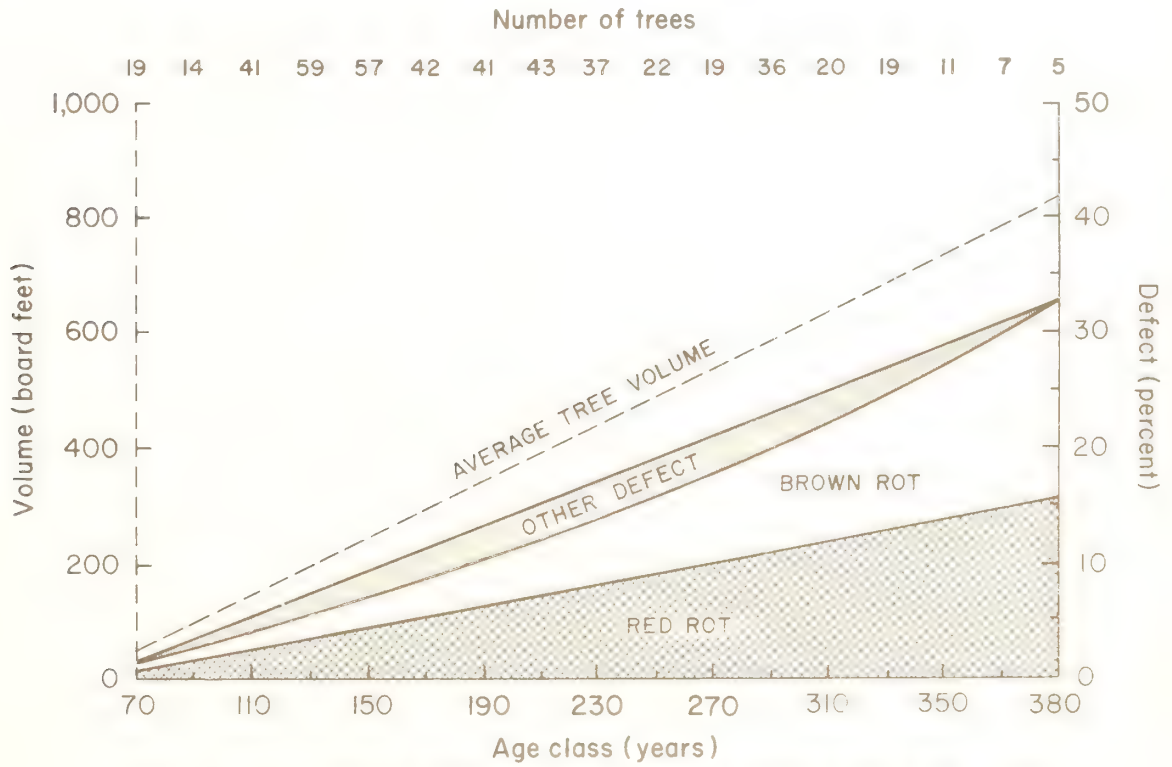

Figure 4.--Relationship between tree age and (1) average gross tree volume and (2) percent defect for ponderosa pine stemwood in the South Units.

rot defect amounted to 10 percent (board-foot basis) at 200 years. In the Black Hills, red rot defect did not reach 10 percent until age 270 years. Red rot defect in the Southwest amounted to 14 percent at 240 years, 19 percent at 300 years, and 25 percent at 380 years in contrast to 8, 11, and 15 percent, respectively, in the Black Hills. Above tree age of 160 years in the Black Hills, the brown rots begin to play a more important role in defect. At ages of 240, 300, and 380 years, the brown rots were responsible for 7, 10, and 18 percent defect. Total rot defect in the Black Hills amounted to little more than red rot defect in the Southwest under 200 years and nearly equal from 200 to 300 years, differing only by 1 or 2 percent. Beyond tree age of 300 years, rot defect was greater in the Black Hills pine.

Andrews and Gill (1941) did not find red rot in the heartwood of immature Black Hills pines under 80 years old, but both incidence and volume increased rapidly after tree age 80. Five trees under 80 years of age contained measurable amounts of red rot in the heartwood in this study. Once red rot has entered the trunk, time is one of the most important factors influencing dimensions of the rot columns. Small pockets of rot may be hidden or too small for scalable defect for many years. The lag between the time red rot reaches the heartwood and the development of scalable defect (table 4) strengthens arguments for shorter rotation periods in the Black Hills.

Table 4.--Relationship of tree age to red rot infection and scalable red rot defect

Tree age class (Years)	Number of trees	Trees with--	
		Infection	Scalable defect
		- - - Percent - - - -	
60-100	33	18	3
101-140	100	38	14
141-180	99	57	22
181-220	84	76	50
221-260	59	69	59
261-300	55	85	74
301+	62	81	69

Andrews and Gill (1941) found no increase in the percent of butt logs infected with red rot after trees reached the age of about 100 years. By this time, the lower dead branches have fallen or ceased to be entrance points of red rot. Infection points are then established through dead branches higher on the trunk. This progressive infection pattern is important in understanding the defect caused by multiple red rot infections.

Brown rot defect was fairly well distributed throughout the trunk, even though a larger percentage of the butt logs was infected. Six trees in this study were complete culls, and brown rot was responsible for 75 percent of the defect in them. It was more important as a culling factor in the butt log than red rot.

Brown rot was found in only one tree under 80 years old. Incidence of infection increased to 29 percent in the 181- to 220-year age class and to 68 percent in the 301+ class. Scalable brown rot defect was found in 21 and 58 percent of the trees in these tree age classes. Brown rot was more important in the older trees and in the butt logs which contain the greater volumes.

Rot defect can be expected to be less when trees are grown on a shorter rotation period, and cull due to other defects should also decrease. As seen in figure 4, other defects remained small over all ages. Defects other than rot were found in 29 percent of the butt logs (table 2). Old fire scars, the main cause of butt defect, can be expected to decrease in the future with increased fire prevention and control. Forks and dead tops were the major cause of other defects in 57 percent of the logs above the third log. Since stand improvement procedures discriminate against such trees, this type of defect will also decline in the future.

Heart rot losses in sawtimber stands will continue to be large until all older trees have been harvested. Losses will probably amount to at least 15 percent in trees older than 200 years (fig. 4). Rot will continue to be the greatest cause of defect, even in second-growth stands on a 120-year rotation. In such stands red rot losses should not exceed 3 percent, brown rot 2 percent, and other defects 2 percent, for a total of about 7 percent defect. Commercial thinnings may reduce this defect slightly.

Hidden Defect

The presence of interior defect—mainly heart rot—is usually revealed on the ends of saw logs after trees have been felled and bucked. Interior defect that is not so exposed or which is not visible to the scaler is referred to as hidden defect. Of the 1,725 logs in the study, 51 percent were classified as sound; that is, they contained no visible defects before being cut into boards. After sawing, however, only 36 percent of the logs were found to be sound (table 5). Although 15 percent of the logs contained hidden decay, this additional defect did not change the board-foot defect percentage for the study sample. The gross scaled volume of logs with hidden defect amounted to 28,910 board feet, whereas 29,100 board feet of rough dry lumber was produced from them. On a cubic-foot basis, this hidden defect amounted to 0.6 percent of the total volume.

Table 5.--Prevalence of logs with hidden rot defect (board-foot basis)

Classification	Logs with rot defect			
	Before sawing		After sawing	
	No.	Percent	No.	Percent
Sound	872	51	620	36
Defective	594	34	846	49
Cull	259	15	259	15
Total	1,725	100	1,725	100

Diagnostic Criteria for Red Rot

Red rot is difficult to detect in standing living trees because fruiting bodies are rarely formed on them, and then only on dead branches infected by the fungus. This type of fruiting merely implies the presence of advanced decay in the branch; it does not indicate the vertical extent of heart rot as do Fomes pini sporophores or swollen knots on Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco var. menziesii). Although the lower trunks of mature and overmature trees rarely are completely clear, decayed branches are most likely to be overgrown. On the other hand, the stubs of decayed branches often protrude from the upper trunk, but it is usually impossible to tell from the ground whether they are decayed by red rot or other branch decay fungi. Suspected red rot entrance points in the upper trunk of merchantable trees can sometimes be confirmed by examining matching branch parts on the ground near the base of the trees. The red rot fungus causes the bark to become firmly attached to the wood, a criterion that distinguishes red rot from other decays.

Since neither fruiting bodies nor rotten branches and branch stubs are reliable indicators for heartwood decay, a number of factors were analyzed to determine if any one or combination could be used as indicators of red rot. These factors were bark retention on dead branches, bark distortion or pseudodefect on the surface of the trunk bark that usually has little or no relation to the quality of the wood beneath; other surface defects such as bark pockets, bird peck, bumps, burls, cankers, scars, sweep, branch clusters, and sucker limbs; and height to first live and dead branch. None was found to be a consistent indicator of decay.

Even after trees have been felled and cut into logs, estimates of volume losses are subject to error because (1) hidden decay, and (2) rot visible on the cut ends of logs do not necessarily indicate the volume of wood decayed.

If rot is visible on both ends of a log, it is usually assumed that the rot extends completely through the log. When rot is visible only at one end of a log, the extent of rot penetration into the log is highly variable. Data from Lightle and Andrews (1968) indicated that, in the latter type of log, the area of the log end (inside bark), the area of heartwood, and the total and advanced red rot areas seemed to be related to the volume of rot in the log. Correlation analysis based on 124 study logs in their study was not significant, but indicated the best criterion of defect volume might be the area of advanced red rot. Data from an additional 180 logs from this study still did not improve their results.[4]

Since infection occurs through dead branches, the possibility of multiple entrance points throughout the tree trunk increases with tree age. Once rot reaches the heartwood, it may spread up and down the trunk and coalesce with other decay pockets. Thus in mature trees the decay may be

[4] *Personal communication with Dr. Paul C. Lightle.*

one long column, many small columns, or a combination of both. The length of red rot decay columns is therefore so variable that volume losses in a living tree cannot be reliably estimated.

Defect in Relation to Parent Soil Material

Conclusions from a previous lumber recovery study indicated that, in general, defect is more prevalent and severe on nonlimestone than limestone areas in the Black Hills (Kotok and Newport 1956). Of the five locations sampled in our study, two were on limestone and three were in areas where the parent material was granite. On limestone areas, 55 percent of the trees had red rot and 35 percent had brown rots as contrasted with 77 and 38 percent, respectively, on the granite areas. The differences were not statistically significant at the 10 percent level, however, due in part to the influence of age; 61 percent of the trees on the limestone areas were under 160 years old, compared to only 38 percent on the granite areas.

Rot Defect and Associated Fungi

Decay studies usually rely on cultural determination of the decay organisms because identification based on rot alone is sometimes erroneous, although red rot (fig. 5) and brown rots (fig. 6) have different characteristics and are easily separated.

Figure 5.--Cross section of a log containing red rot. Advanced decay usually results in a cavity around the knot in which the decay entered the trunk heartwood. Incipient decay then radiates outward from the trunk in a spoke-like manner.

It was not possible, however, to make isolations from columns of decay in logs that were to be cut into boards. Isolations from cull logs in the field allowed a partial identification of rot columns in these adjacent logs which were cut in the mill.

A total of 426 isolations were made from decay: 278 from white-pocket rot assumed to be red rot, and 148 from brown rot. Of the suspected red rot cultures, 236 were identified as P. anceps. Only 28 of the brown rot cultures were identified and another 20 were grouped into three definite unknown species. The remainder of the cultures were either contaminated or could not be identified.

While most Polyporus anceps in this study was identified only by its white-pocket rot, the many cultures of P. anceps taken from rot in the cull logs suggest that the determinations were generally valid. However, because P. anceps is presently undergoing taxonomic study, some reservations must be made concerning the decay ascribed to the organism. The apparent lack of other white-pocket rot fungi in the Black Hills pine remains questionable. Several cultures from white-pocket rots remain unidentified and may later be described as other species of decay fungi.

All identifications of specific brown rot organisms were from cultures isolated from cull logs. No attempt was made to differentiate between the species of brown rots on the exposed log ends because information is lacking on the causal fungi.

The high proportion of brown rots was unexpected; over a third of the trees in this study were

Figure 6.--Cross section of a log containing brown cubical rot which entered through a large dead branch. Advanced decay usually results in a circular cavity in the trunk heartwood. Incipient decay is usually circular in shape and often regular in outline.

infected. Of the 11 or more suspected species of brown-rotting fungi involved, only 5 have been identified. Table 6 lists the known brown rot fungi and the amount of defect they caused. Defect volumes attributed to the various brown rot fungi in table 6 cannot be compared because only 17 percent of the brown rot volume was identified.

Veluticeps berkeleyi caused extensive butt and trunk rot and cull in older trees (205-300 years), and may be the most damaging brown rot of pine in the Black Hills. Entrance points of decay were old fire wounds and dead branch stubs. The decay columns were extremely long, extending in a continuous column for distances of 50 to 80 feet, often to within 10 feet of the tree top. The identity of the decay organism remained in question until 1966 when it was established in a sporophore study of the fungus (Gilbertson et al. 1968).

Prior to the study, Polyporus schweinitzii was suspected of causing most of the brown rot in the Black Hills. It gains entrance through basal wounds such as fire scars, and causes extensive butt rot in older trees. Its apparent importance as a butt rot would probably have been greater if all butt rots had been identified.

Coniophora puteana is a fairly common decay fungus in living Engelmann spruce, Picea engelmannii Parry, (Hinds and Hawksworth 1966) and subalpine fir, Abies lasiocarpa (Hook.) Nutt. (Hinds et al. 1960) in Colorado. The single isolation of this organism from ponderosa pine in the Black Hills does not necessarily mean that it is of minor importance. It caused a 30 percent defect in the tree from which it was isolated, and was no doubt present in others.

Merulius himantioides is usually a decayer of slash and has been associated with the deterioration of beetle-killed Engelmann spruce (Hinds et al. 1965). It was associated with old trunk wounds in this study, and caused only minor amounts of defect.

The importance of Poria alpina as a decay of conifers remains to be determined, for its cultural identification has only recently been completed.

Before any meaningful conclusions can be drawn about the relative importance of the brown rots, other fungi will have to be identified by intensive sporophore collecting, and additional decay studies will be required.

Sporophores and cultures of other decay fungi found on ponderosa pine slash in the Black Hills were:

Armillaria mellea (Fr.) Quel.
Coniophora spp. (four species)
Cristella sulphurea (Pers. ex Fr.) Donk.
Fomes pinicola (Swarts ex Fr.) Cke.
Hyphodontia aspera (Fr.) Erikss.
Lenzites saepiaria Wulf. ex Fr.
Merulius americana Fr.
Merulius sp.
Peniophora gigantea (Fr.) Mass.
Peniophora spp. (two species)
Polyporus dichorous Fr.
P. sanguineus L. ex Fr.
P. sulphureus Bull. ex Fr.
Poria cinerascens Bres.
P. rixosa Karst.
P. vaporaria (Pers. ex Fr.) Cke.

Table 6.--Fungi associated with brown rot

Fungus	Number of trees	Total tree volume		Average percent defect	
		Bd. ft.	Cu. ft.	Bd. ft.	Cu. ft.
Veluticeps berkeleyi Cooke	3	1,910	343.9	53	37
Polyporus schweinitzii Fr.	3	1,390	242.3	35	14
Coniophora puteana (Schum. ex Fr.) Karst	1	610	107.8	30	16
Poria alpina Litsch.	5	2,750	513.8	20	10
Merulius himantioides Fr.	2	970	196.5	5	1
Total	14	7,630	1,404.3	50	16

Poria spp. (two species)
Trametes americana Overh.
Varia grandulosa (Pers. ex Fr.) Lau.

Some of these fungi are known to cause decay in living trees, while others are slash decay organisms. Their role in decay of living trees in this study was not determined.

Summary

Rot losses in sawtimber pine stands in the Black Hills were evaluated in conjunction with a lumber grade recovery study. Boards with decay cut from 1,468 logs of 498 trees from five areas were photographed after being sawed in the mill. Supplemental data were obtained from log diagram forms and 257 dissected cull logs in the woods. Decay fungi were isolated from cull logs.

Total defect for all trees amounted to 19.2 percent of the gross volume; red rot caused by *Polyporus anceps* was responsible for 8.6 percent and brown cubical rots 7.3 percent. The remaining 3.3 percent was attributed to defects other than rot. The relationship between average defect, tree gross volume, and tree age was analyzed. Rot losses amount to over 15 percent in trees older than 250 years, about 7 to 11 percent in trees less than 200 years old, and about 7 percent in trees 150 years old. Rot will continue to be the greatest cause of defect even in second-growth stands on a 120-year rotation. In such stands, red rot losses should be about 3 percent, brown rot 2 percent, and other defects 2 percent.

Red rot was present in 68 percent of all trees and in 26 percent of the logs, whereas brown rot was present in 36 percent of all trees and in 12 percent of the logs. Only 36 percent of the logs were free from defect. *Veluticeps berkeleyi* and *Polyporus schweinitzii* appear to be the important brown rot fungi; but only a small volume of the total brown rot volume has been identified.

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A defect study of 1,725 logs cut from 498 trees provided the basis for determining the relationships between tree age, volume, and defect. Red rot was responsible for 8.6 percent, brown rots 7.3 percent, and other defects 3.3 percent of the total 19.2 percent defect. Red rot, found in 68 percent of all trees, was the most important cause of defect.

Key words. Polyporus anceps Pk., Pinus ponderosa, lumber quality, tree volume estimates.

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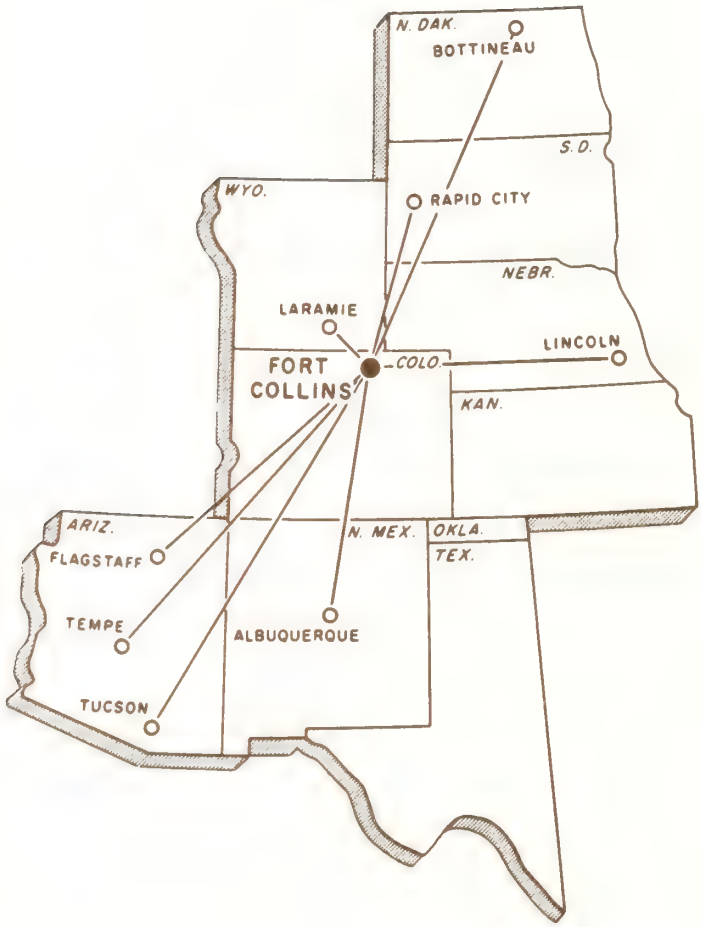
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ıreal snow cover and disposition of nowmelt runoff in central colorado

y Charles F. Leaf

ocky Mountain Forest and Range Experiment Station - Forest Service - U.S. Department of Agriculture
tmospheric Water Resources Program, Bureau of Reclamation - U.S. Department of the Interior

Abstract

Areal snow-cover depletion and resultant snowmelt and water yield were studied on three small watersheds in the Fraser Experimental Forest.

High water yield efficiencies were observed on two watersheds which had: (1) almost complete snow cover when seasonal snowmelt rates on all major aspects were maximum; (2) a delayed and short snow-cover depletion season; and (3) moderate recharge and evapotranspiration losses.

Water yield efficiency in one watershed with low-elevation south slopes was least. In 1969, streamflow from the drainage area on this basin below 9,850 feet was less than 30 percent of that generated from above this elevation. Fourteen years of comparative streamflow indicated that water yields from the low-elevation subdrainage can vary from near zero in poor runoff years to a maximum during good years of about 50 percent of the flow generated from the high-elevation subdrainage.

Key words: Aerial photography, runoff, snow surveys, stream gaging, hydrologic cycle.

ABOUT THE COVER:

Snow cover in Byers Creek Basin, Fraser Experimental Forest, June 1970.

USDA Forest Service
Research Paper RM-66

March 1971

Areal Snow Cover and Disposition of Snowmelt Runoff in Central Colorado

by

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[1]Central headquarters maintained at Fort Collins in cooperation with Colorado State University. Research reported here was conducted and partly financed in cooperation with the Bureau of Reclamation, U. S. Department of the Interior.

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Areal Snow Cover and Disposition of Snowmelt Runoff in Central Colorado

Charles F. Leaf

Introduction

The processes which produce stream runoff from snowmelt are too varied and too complex to be completely defined at this time. Hence, relatively simple relationships have been derived which empirically relate the more important factors in the hydrologic cycle for practical usage. Included in these types of relationships are correlations of the areal extent of snow cover with snowpack volume and streamflow. Such relationships have important application in (1) operational streamflow forecasting, and (2) hydrologic analysis of snow zone watersheds.

Streamflow Forecasting

Depletion-runoff relationships were first used for operational streamflow forecasting more than 30 years ago by Gross (1937), Parshall (1941), and Potts (1944). These early forecasting procedures were based on index observations of snow cover by ground photographic methods. In the 1950's, depletion-runoff forecast curves were developed by several investigators from estimates of total snow coverage on drainage basins (Brown and Dunford 1956, Garstka et al. 1958, Miller 1953, Parsons and Castle 1959). Thoms (1961) discussed residual volume forecasting procedures and summarized observations of areal snow cover in the Columbia River Basin since 1951. More recently, a supplement to this work has been published, which extends the summary through the 1968 spring runoff season (Thoms 1969, Thoms and Wang 1969). Leaf (1969), who summarized integral estimates of snow cover in central Colorado, derived residual volume forecast curves for three small experimental watersheds, based on records from the 1964 through 1968 snowmelt runoff seasons.

Hydrologic Analysis

Several of the investigators cited above have pointed out that every watershed has a characteristic relationship between snowpack depletion and the disposition of snowmelt runoff which can be explained by (1) geologic and topographic variability, and (2) the amount and distribution of forest cover. In other words, the empirical relationships derived for a given watershed apply only to that watershed, and reflect the effects of terrain diversity as well as ground water storage, and evapotranspiration losses. In addition to physiographic variations between watersheds, these correlations are also influenced by (1) the initial volume of the snowpack each year, and (2) meteorological conditions during each snowmelt runoff season. The effects of many of these factors are discussed in detail by Miller (1953) and the Corps of Engineers (U.S. Army 1956).

Areal snow-cover depletion, if correlated with (1) ablation (or melt) of the snowpack water equivalent, and (2) resultant streamflow, can provide a better understanding of the hydrology of snow zone watersheds. This report discusses the areal extent of snow cover in relation to the water balance on three small watersheds.

Study Area

The three study watersheds (figs. 1-3) are part of the Fraser Experimental Forest near Fraser, Colorado. They are tributary to flow of the Upper Colorado River Basin. Lodgepole pine and spruce-fir are the important forest types.[2] Deep, gravelly

[2] *Lodgepole pine* [illegible]
Engelmann spruce (Picea engelmanii)
Subalpine fir (Abies lasiocarpa)

Figure 1.--Fool Creek experimental watershed. Timber was removed from Fool Creek in 1954-56 to determine the effects of harvest cutting on streamflow.

Figure 2.--Lexen (left) and Deadhorse (right) experimental watersheds, Fraser Experimental Forest.

Figure 3.-- Fool Creek watershed before harvest cutting.

soils overlay Pre-Cambrian bedrock; glaciation has influenced the topography. More detailed discussions of the geology, climate, and water yields are found in Garstka et al. (1958), Hoover (1967), Leaf (1966), Retzer (1962).

Fool Creek Watershed

Snowpack Depletion

On Fool Creek, one of several gaged watersheds in the Fraser Experimental Forest, we are currently studying how harvest cutting influences streamflow (Hoover 1969, Hoover and Leaf 1967, Martinelli 1964). Treatment of this 714-acre watershed began in 1954 and was completed in 1956. Elevation of the watershed ranges from 9,600 feet at the stream gage to about 11,500 feet, and slopes average 26 percent. The main channel flows north; generally east- and west-facing aspects comprise 70 percent of the watershed area. Thus, radiant energy incident on the watershed surface is fairly uniform during the snowmelt runoff season.

The watershed research program on Fool Creek began in 1940. Observations during the pretreatment period (1940-54) generally began in early April and continued at periodic intervals through the snowmelt season. In 1952 greater coverage of the watershed was obtained through installation of additional snowcourses. This discussion is based on comparisons with the snowcourse data collected during the 1952 snowmelt runoff season.

Each of 32 snowcourses established in 1952 was a sample plot 1 chain wide by 12 chains long (fig. 4). Twelve sample points were measured at 1-chain intervals on each plot. In addition to the plot snowcourses, concurrent measurements were made on a 3.5-mile-long "figure-eight" snowcourse.

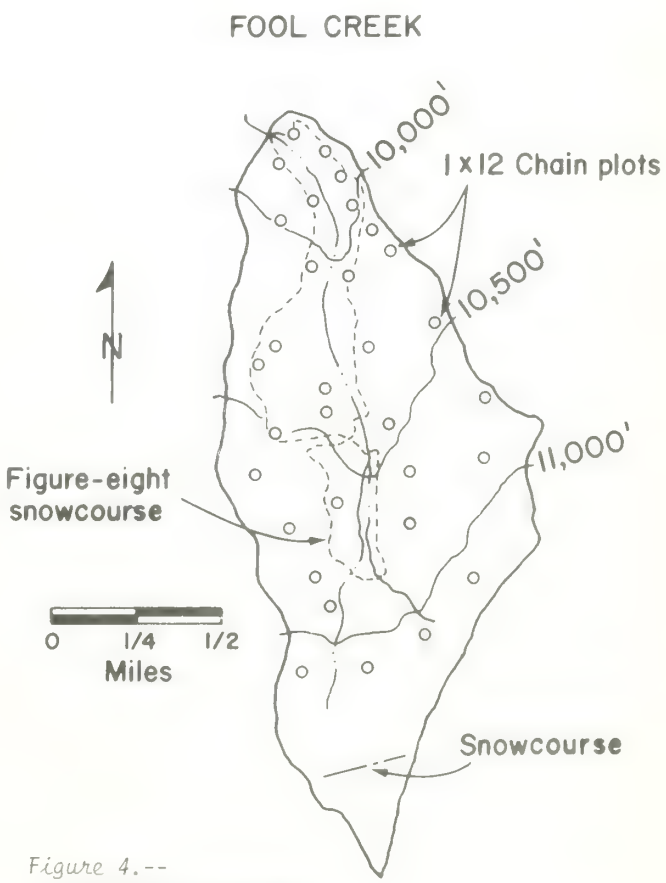

Figure 4.-- Snowcourse locations on Fool Creek, 1952.

The data from 50 sampling points on this course were included along with a snowcourse near timberline. Sampling began April 10 and continued at weekly intervals through June 27, 1952 on the plots and figure-eight snowcourse. The upper course was surveyed on April 25. Individual measurements from all the sample points in the basin were used to estimate snow disappearance. Fool Creek was divided into six subunits, primarily on the basis of orientation since there were no abrupt changes in slope steepness and vegetation below timberline. Above 11,100 feet, forest cover is sparse, and the slope is gentle. This area was delimited as a separate subunit. Total watershed snow cover was determined by means of a weighted average based on the area and estimated snow cover in each subunit. These values were also weighted by means of the area-elevation curve to obtain an areal index of the input. Summaries of peak water equivalent and precipitation during snowmelt are shown for each elevation zone on the two major aspects of Fool Creek in table 1.

Runoff

Runoff from Fool Creek is gaged by a San Dimas flume (Garstka et al. 1958). The streamflow hydrograph for 1952 is plotted in figure 5. Because there is considerable storage delay of snowmelt inputs to the watershed, the hydrograph was separated into generated components. Generated runoff is defined as that quantity of snowmelt which results as streamflow. The flow generated during a given melt interval is obtained from the discharge hydrograph by means of the recession curve. In general,

Table 1.--Estimated peak water equivalent and subsequent precipitation on Fool Creek, 1952

Aspect and zone[1]	Mean elevation	Peak water equivalent	Precipitation subsequent to peak water equivalent										
			Apr. 25	May 1	May 24	May 29	June 5	June 12	June 20	June 27	July 1	Total	Total seasonal
	Feet	Inches											
EAST ASPECT:													
1	9,750	14.4	0.92	0.56	1.03	1.48	0.24	1.01	0.05	0.11	0.33	5.73	20.1
2	9,900	15.6	.88	.57	1.03	1.46	.24	1.00	.05	.11	.32	5.66	21.3
3	10,050	16.8	.39	.58	1.04	1.44	.24	.99	.05	.12	.30	5.64	22.4
4	10,190	18.0	.87	.60	1.03	1.42	.25	.98	.05	.12	.28	5.60	23.6
5	10,310	19.0	.85	.72	1.03	1.40	.25	.96	.05	.12	.28	5.63	24.6
6	10,410	19.8	.84	.81	1.09	1.40	.50	.81	.05	.13	.23	5.86	25.7
7	10,510	20.5	.83	.90	1.11	1.38	.81	.45	.05	.13	.22	5.88	26.4
8	10,620	21.4	.82	1.00	1.14	1.36	1.20	.06	.05	.14	.20	5.97	27.4
9	10,850	23.2	.80	1.22	1.43	1.34	1.22	.06	.05	.15	.18	6.45	29.6
10	11,100	25.2	.78	1.46	1.73	1.28	1.24	.06	.05	.16	.14	6.90	32.1
Total		193.9	8.48	8.42	11.66	13.96	6.19	6.38	.50	1.29	2.45	59.33	253.2
Mean		19.4	.85	.84	1.17	1.40	.62	.64	.05	.13	.24	5.93	25.3
WEST ASPECT:													
1	9,810	12.6	.90	.10	1.30	1.41	.41	.95	.10	.10	.30	5.55	18.1
2	10,025	14.6	.92	.11	1.49	1.40	.47	1.05	--	.11	.28	5.83	20.4
3	10,140	16.1	.89	.33	1.54	1.39	.61	1.00	--	.12	.27	6.15	22.2
4	10,350	17.6	.85	.70	1.33	1.38	.92	.57	--	.12	.26	6.13	23.7
5	10,540	19.3	.81	1.16	1.09	1.37	1.28	.08	--	.13	.25	6.17	25.5
6	10,720	20.9	.78	1.26	1.32	1.36	1.32	.06	--	.14	.24	6.48	27.4
7	10,865	22.2	.75	1.29	1.58	1.35	1.33	.06	--	.15	.23	6.36	28.6
8	10,985	23.4	.72	1.32	1.75	1.34	1.34	.06	--	.15	.22	6.90	30.3
9	11,110	24.5	.68	1.35	1.93	1.34	1.35	.06	--	.16	.21	7.08	31.6
10	11,280	26.1	.66	1.40	2.19	1.33	1.36	.06	--	.17	.20	7.37	33.5
Total		197.3	8.04	9.02	15.52	13.67	10.39	3.95	.10	1.35	2.46	64.02	261.3
Mean		19.7	.80	.90	1.55	1.37	1.04	.39	.01	.13	.25	6.40	26.1

[1]Each zone represents 10 percent of the watershed area.

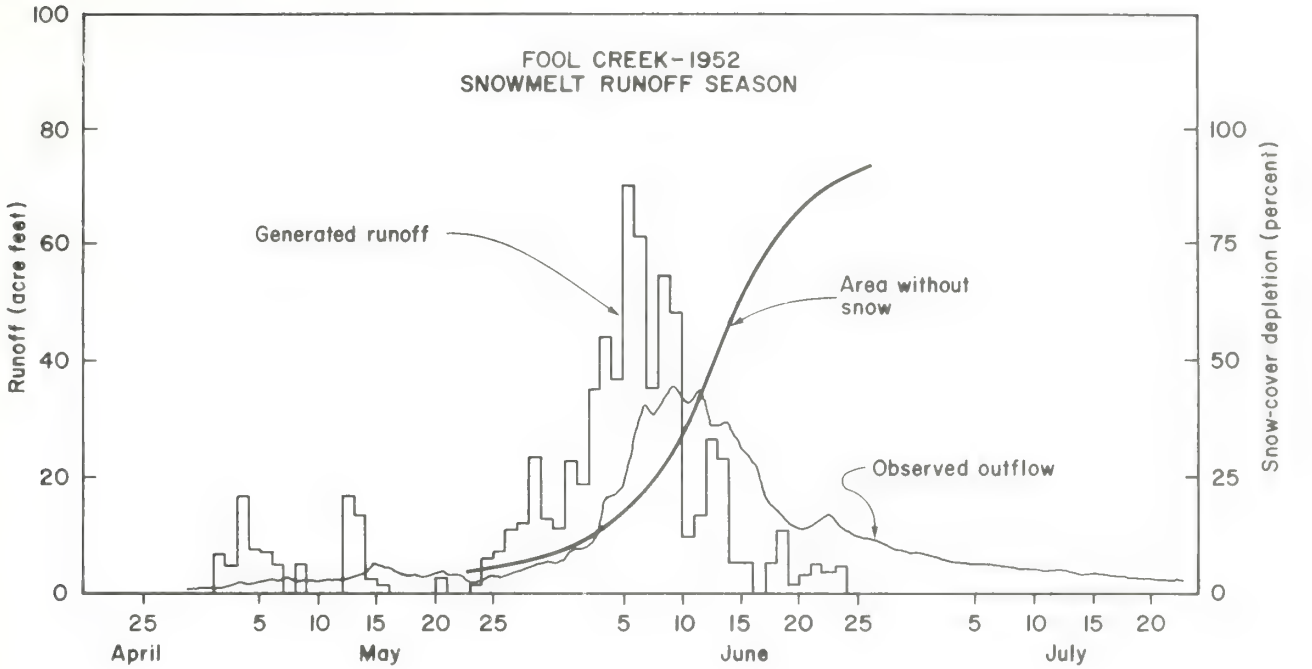

Figure 5.--Summary of snow-cover depletion, generated runoff, and observed outflow from Fool Creek, 1952 snowmelt runoff season.

the procedure for deriving generated flows is to (1) compute the volume observed during the interval, (2) add the volume beneath the recession curve (storage volume) at the end of the interval, and (3) subtract the storage volume which existed on the watershed at the beginning of the interval. The procedure and reasoning behind this approach is discussed in detail by the U.S. Army (1956) and Garstka et al. (1958). Table 2 summarizes flows generated during each snowmelt day for the 1952 runoff season.

Precipitation Input and Melt

Indices of precipitation input and ablation were derived by means of "snow charts" proposed by the Corps of Engineers (U.S. Army 1956). In this procedure, average values of snowpack water equivalents on the various snowcourses were plotted according to their respective elevations and weighted according to the area-elevation curve. Precipitation after peak snowpack water equivalent was measured by a network of 15 standard 8-inch gages along the figure-eight snowcourse.

Deadhorse and Lexen Watersheds

Snowpack Depletion

Deadhorse and Lexen Creek (see fig. 2) flow east and drain 667 and 306 acres, respectively. Elevations range from 9,450 feet at Deadhorse stream gage and 9,850 at Lexen gage to 11,600 feet. In contrast to Fool Creek, these watersheds are steeper, with side slopes averaging almost 40 percent. The north and south exposures, particularly at the lower elevations, provide unequal heat supply.

Aerial photography has been used to observe snow-cover depletion since 1964. Photos are taken at about 10-day intervals after snowmelt begins on Deadhorse and Lexen. Oblique photographs were taken through the 1964 melt season. In 1965 and subsequent years, vertical photographs with an approximate photo scale of 500 feet to the inch were obtained in cooperation with the Office of Atmospheric Water Resources, USDI Bureau of Reclamation.

The extent of snow cover on the photographs was estimated visually with the aid of a folding stereoscope; these estimates were transposed to

Table 2.--Seasonal generated runoff above 0.3 c.f.s. baseflow from Fool Creek during 1952 snowmelt runoff season

Month and day	Generated runoff			Month and day	Generated runoff		
	Daily	Cumulative			Daily	Cumulative	
	Acre-ft.	Acre-ft.	Percent		Acre-ft.	Acre-ft.	Percent
May				June			
2	7.02	7.07	1.0	3	34.98	250.60	35.1
3	4.59	11.66	1.6	4	44.10	294.70	41.3
4	16.82	28.48	4.0	5	37.45	332.15	46.5
5	7.71	36.20	5.1	6	69.66	401.81	56.3
6	7.14	43.34	6.1	7	61.00	462.81	64.9
7	5.12	48.45	6.8	8	35.17	497.98	69.8
9	5.18	53.64	7.5	9	53.39	551.37	77.3
13	16.52	70.16	9.8	10	47.96	599.33	84.0
14	13.69	83.85	11.8	11	9.74	609.08	85.4
15	1.88	85.73	12.0	12	13.61	622.69	87.3
16	1.44	87.17	12.2	13	26.33	649.02	91.0
21	2.72	89.89	12.6	14	23.03	672.05	94.2
24	.89	90.78	12.7	15	5.06	677.11	94.9
25	6.19	96.97	13.6	16	4.94	682.06	95.6
26	6.79	103.75	14.5	18	5.41	687.47	96.3
27	10.96	114.72	16.1	19	10.97	698.43	97.9
28	11.79	126.50	17.7	20	1.02	699.46	98.0
29	23.64	150.14	21.0	21	2.27	701.72	98.3
30	12.81	162.96	22.8	22	4.58	706.31	99.0
31	11.25	174.20	24.4	23	3.11	709.41	99.4
June							
1	23.25	197.46	27.7	24	4.17	[1]713.58	100.0
2	18.17	215.63	30.2				

[1]Total seasonal generated runoff; observed outflow to June 24, 1952, 578.59 acre-feet.

subdivided base maps of each watershed. As on Fool Creek, watershed subunits were delimited on the basis of orientation, vegetation, and slope steepness. The total watershed snow cover was determined by computing a weighted average based on the area and extent of snow cover in these subunits. For reasons discussed below, Deadhorse Creek was divided into an upper and lower basin (fig. 6).

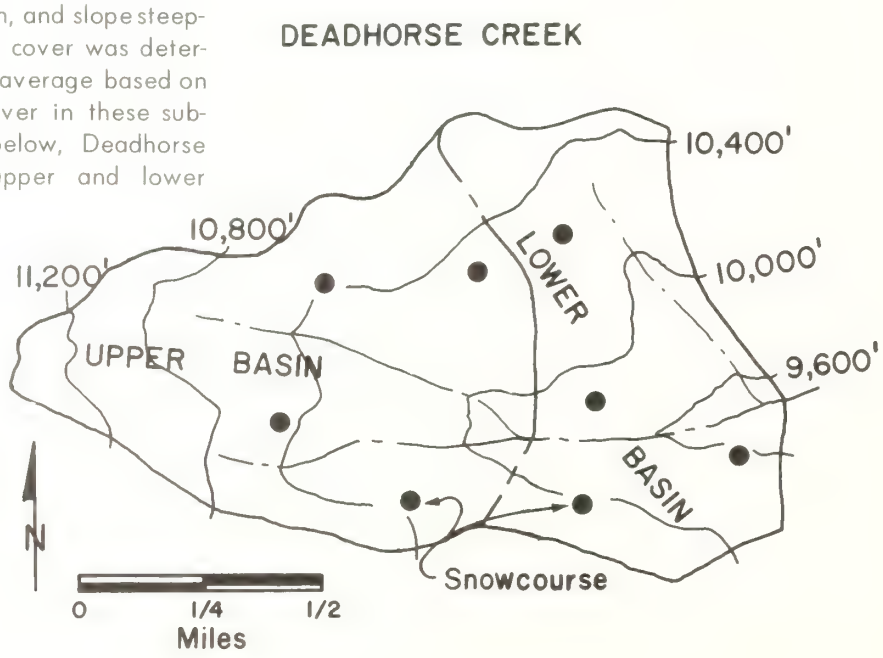

Figure 6.--Snowcourse locations on Deadhorse Creek, 1969.

Runoff

Streamflow from Deadhorse and Lexen watersheds is gaged by 120° V-notch weirs. Snowmelt runoff hydrographs for the 1969 season are plotted in figure 7. Flows generated during five of the six time intervals in figure 7 are summarized in table 3. Seasonal totals are based on flows gen-

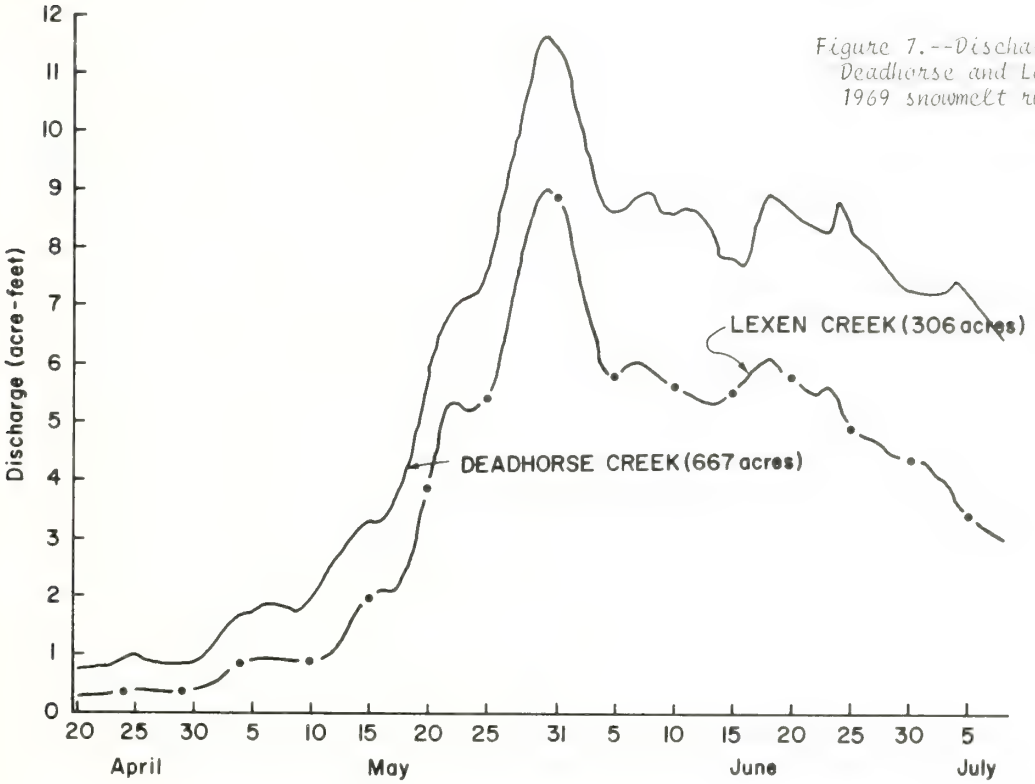

Figure 7.--Discharge hydrographs of Deadhorse and Lexen Creeks during 1969 snowmelt runoff season.

Table 3.--Seasonal generated runoff[1] from Deadhorse and Lexen Creeks during 1969 snowmelt runoff season

Interval	Generated runoff on--					
	Deadhorse Creek			Lexen Creek		
	During interval	Cumulative		During interval	Cumulative	
	Acre-ft.	Acre-ft.	Percent	Acre-ft.	Acre-ft.	Percent
April 16 to April 30	24.5	24.5	5.7	10.6	10.6	3.6
April 30 to May 21	179.1	203.6	47.6	189.2	199.8	67.2
May 21 to May 28	148.9	352.5	82.3	42.2	242.0	81.3
May 28 to June 4	25.4	377.9	88.3	15.5	257.5	86.5
June 4 to June 11	50.1	[2]428.0	100.0	40.0	[3]297.5	100.0

[1]Above an assumed constant baseflow of 0.2 and 0.1 cubic foot per second on Deadhorse and Lexen Creeks, respectively.
[2]Total seasonal generated runoff; observed outflow to June 11, 1969, 368.1 acre-feet.
[3]Total seasonal generated runoff; observed outflow to June 11, 1969, 252.0 acre-feet.

erated through June 11. The unusually high precipitation and resultant streamflow during the last half of June were not included in these summaries, since almost all the seasonal snowpack had already melted.

Precipitation Input and Melt

Estimates of peak seasonal water equivalent and ablation during the melt season were derived from weekly measurements of a network of eight snowcourses, each with eight sample points, on the major aspects of Deadhorse Creek (see fig. 6). Average snowcourse water equivalents were plotted according to elevation; these relationships were used to estimate the amount of snowpack in each of 22 watershed subunits. A weighted index of areal water equivalent was then computed, based on the estimated snowpack water equivalents in each subunit. Precipitation input after peak seasonal snowpack accumulation was estimated from weekly measurements of a network of seven standard 8-inch gages spaced along the access road shown in the lower lefthand corner of figure 2. An arithmetic average of the seven gages was assumed to be the best estimate of areal precipitation on Deadhorse Creek. Peak water equivalent and precipitation during snowmelt are summarized in table 4.

Table 4.--Estimated peak seasonal water equivalent and subsequent precipitation on Deadhorse Creek, 1969 snowmelt season

Watershed subunit	Median elevation	Peak water equivalent	Precipitation subsequent to peak [1]							
			Apr. 16	Apr. 30	May 7	May 14	May 21	May 28	June 4	June 11	Total
	Feet	Inches								
LOWER BASIN:											
I	9,650	10.7	0.8	0.8	1.8	0.1	1.0	0.3	0.2	0.9	16.6
II	9,700	11.5	.8	.8	1.8	.1	1.0	.3	.2	.9	17.4
III	9,850	12.0	.8	.8	1.8	.1	1.0	.3	.2	.9	17.9
IV	9,900	12.0	.8	.8	1.8	.1	1.0	.3	.2	.9	17.9
V	10,000	12.5	.8	.8	1.8	.1	1.0	.3	.2	.9	18.4
VI	9,950	12.5	.8	.8	1.8	.1	1.0	.3	.2	.9	18.4
VII	10,000	13.0	.8	.8	1.8	.1	1.0	.3	.2	.9	18.9
VIII	10,100	13.0	.8	.8	1.8	.1	1.0	.3	.2	.9	18.9
XVII	10,600	14.0	.8	.8	1.8	.1	1.0	.3	.2	.9	19.9
XVIII	10,250	12.7	.8	.8	1.8	.1	1.0	.3	.2	.9	18.6
XVIII-A	9,900	10.5	.8	.8	1.8	.1	1.0	.3	.2	.9	16.4
XIX	10,050	11.7	.8	.8	1.8	.1	1.0	.3	.2	.9	17.6
XX	10,350	14.0	.8	.8	1.8	.1	1.0	.3	.2	.9	19.9
XXI	9,950	10.7	.8	.8	1.8	.1	1.0	.3	.2	.9	16.6
Weighted average:		11.9	.8	.8	1.8	.1	1.0	.3	.2	.9	17.8
UPPER BASIN:											
IX	10,250	14.5	.8	.8	1.8	.1	1.0	.3	.2	.9	20.4
X	10,400	14.7	.8	.8	1.8	.1	1.0	.3	.2	.9	20.6
XI	10,200	13.7	.8	.8	1.8	.1	1.0	.3	.2	.9	19.6
XII	10,800	16.0	.8	.8	1.8	.1	1.0	.3	.2	.9	21.9
XIII	11,150	18.0	.8	.8	1.8	.1	1.0	.3	.2	.9	23.9
XIV	10,850	15.0	.8	.8	1.8	.1	1.0	.3	.2	.9	20.9
XV	10,550	15.0	.8	.8	1.8	.1	1.0	.3	.2	.9	20.9
XVI	10,350	14.0	.8	.8	1.8	.1	1.0	.3	.2	.9	19.9
Weighted average:		15.3	.8	.8	1.8	.1	1.0	.3	.2	.9	21.2
Total weighted average:		13.7	.8	.8	1.8	.1	1.0	.3	.2	.9	19.6

[1]Average of seven standard 8-inch gages along access road.

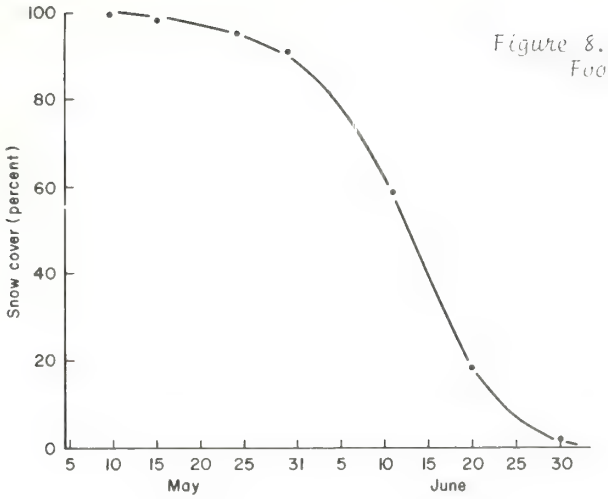

Figure 8.--Sequence of snow-cover depletion on Fool Creek, 1952 snowmelt season.

Analysis and Results

Sequence of Snow-Cover Depletion

The sequence of snow-cover depletion on Fool Creek, Deadhorse, and Lexen watersheds is plotted in figures 8-10. Compared to Lexen Creek, areal depletion of the snowpack on Deadhorse Creek starts earlier as the result of advanced snowmelt on the low-elevation south slopes. The rate of

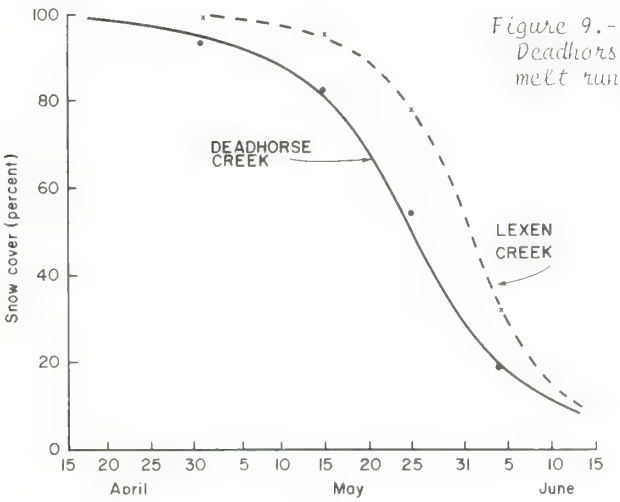

Figure 9.--Sequence of snow-cover depletion on Deadhorse and Lexen watersheds, 1969 snowmelt runoff season.

depletion in the upper basin of Deadhorse Creek (fig. 10) is similar to that of Lexen.

The dates when watershed subunits became bare of snow were estimated to obtain a more complete picture of snowpack depletion. This sequence was approximated by considering an intermediate extent of snow cover (Miller 1953). The dates were expressed as the number of days after April 30, when snowmelt runoff began on Fool Creek in 1952 and on Deadhorse and Lexen in 1967.

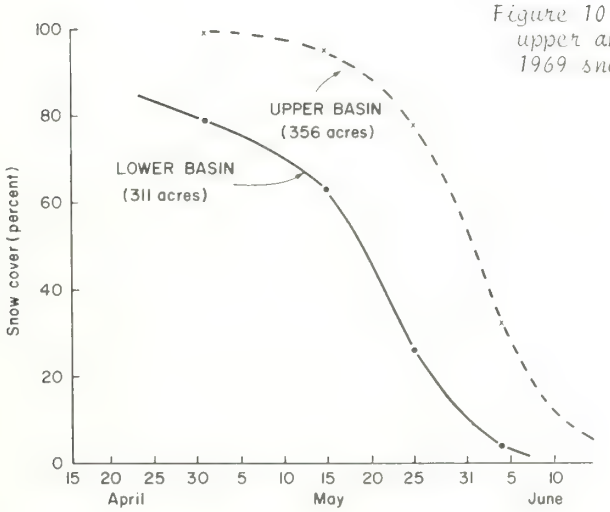

Figure 10.--Sequence of snow-cover depletion on upper and lower basins of Deadhorse Creek, 1969 snowmelt runoff season.

The combined effects of elevation, forest cover, and contrasting orientation on snow-cover depletion are illustrated by the average date when snow cover was reduced to 60 percent of the watershed area:

	Fool Creek	Deadhorse	Lexen
Year	1952	1967	1967
Number of subunits	6	22	11
Number of days after April 30:			
Average	36	28	36
Range	35-53	1-52	22-51
Standard deviation	7	14	9

The snowpack depletion season was longer and depletion rates were more widely dispersed around the watershed mean on Deadhorse Creek. The delayed and shorter snow-cover depletion season on Lexen is apparently more comparable to Fool Creek, since large areas of these watersheds become bare of snow simultaneously.

Snowmelt

Although the following discussion refers primarily to figures 11 and 12, it should be considered to apply to other years. These data are the best estimates available of relative snowmelt according to aspect and elevation at the Fraser Experimental Forest.

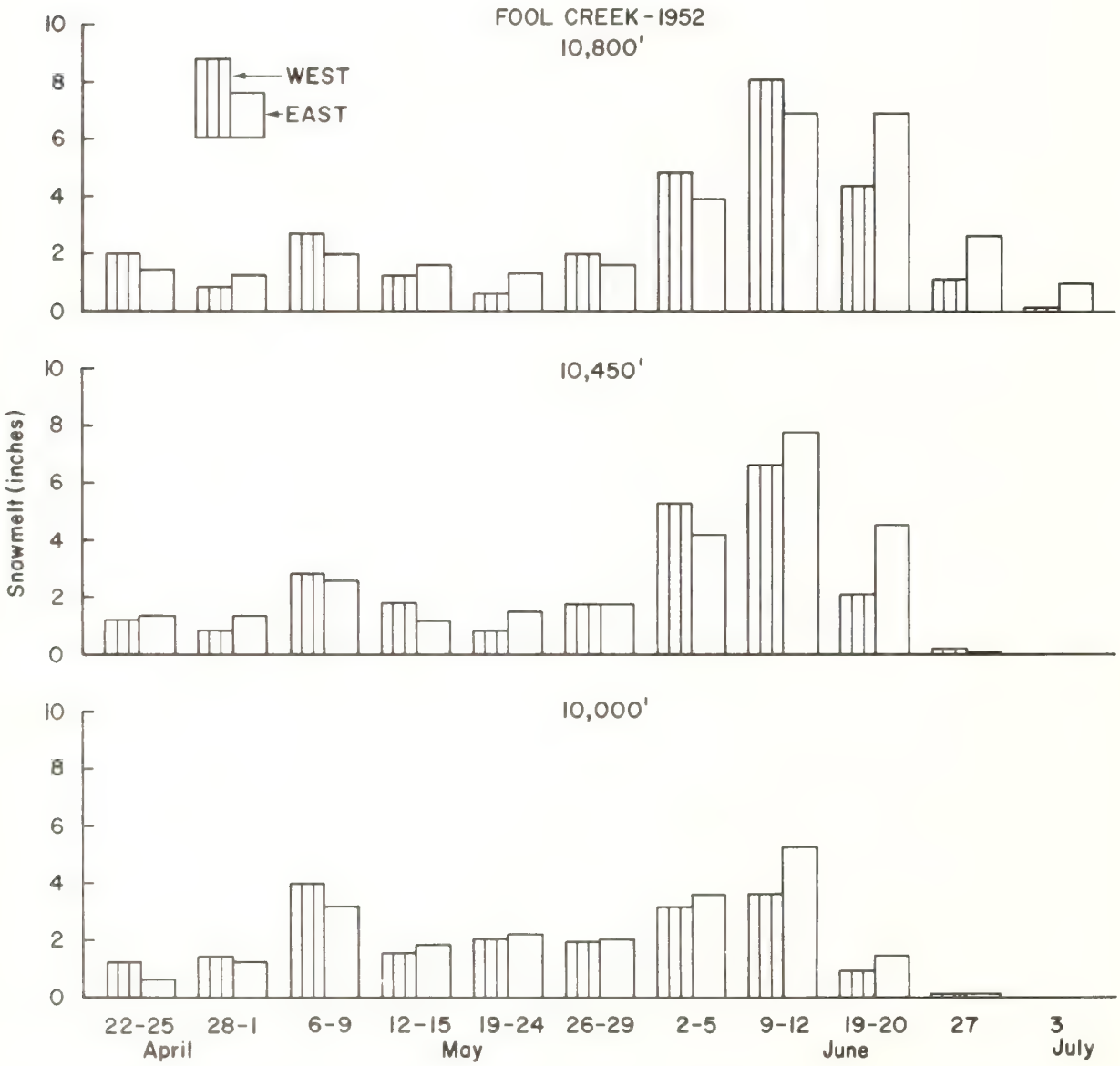

Figure 11.--Relative snowmelt rates at low, intermediate, and high elevations on the east- and west-facing aspects of Fool Creek. The individual bars represent snowmelt corrected for precipitation recorded between each snow-survey interval.

The analysis of peak snowpack accumulation on Fool Creek showed essentially the same average water equivalent on the east- and west-facing aspects (see table 1). Both aspects retained about the same average water equivalent throughout the snowmelt season. Snowpack melt rates were generally similar on both aspects at all elevations on Fool Creek watershed (fig. 11). Areal snowmelt corrected for precipitation after peak water equivalent is summarized in table 5.

Snowpack melt rates differed considerably between the low-elevation north and south slopes of Deadhorse watershed (fig. 12). This agrees with the results of Garstka et al. (1958), who reported that, at 9,500 feet on a watershed adjacent to Deadhorse Creek, melt rates on the south slope

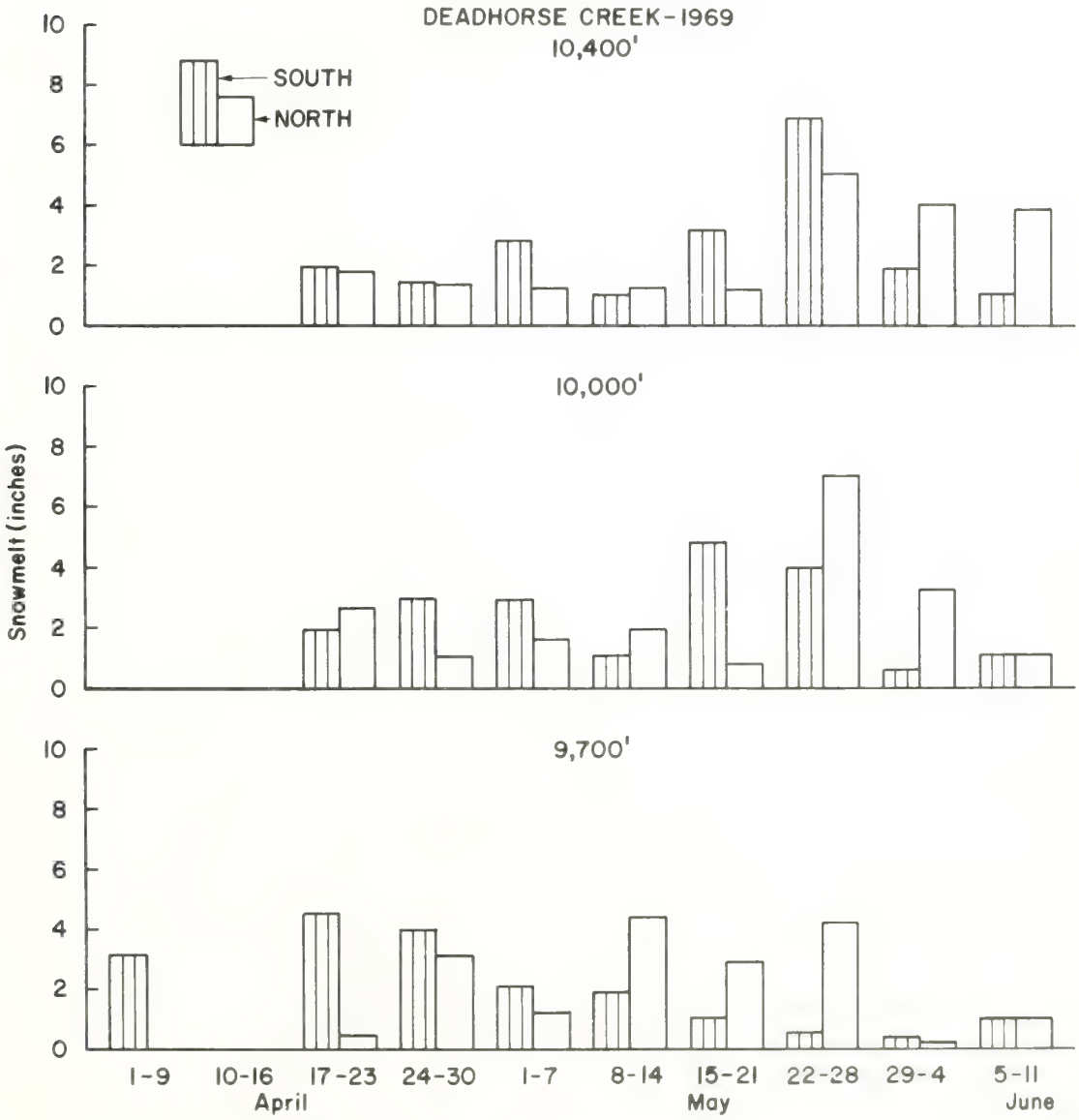

Figure 12.--Relative snowmelt rates at low, intermediate, and high elevations on the north- and south-facing aspects of Deadhorse Creek. The individual bars represent snowmelt corrected for precipitation recorded between each snow-survey interval.

Table 5.--Areal snowmelt on study watersheds, corrected for precipitation subsequent to peak water equivalent

Watershed and measurement periods	Water equivalent, beginning of period	During interval			Cumulative snowmelt	
		Snowmelt	Precipitation	Total		
		- - - - - - Inches - - - - - - -			Inches	Percent
FOOL CREEK, 1952:						
April 16-25	19.6	0.1	0.82	0.92	0.92	3.6
April 25-May 1	19.5	.7	.87	1.57	2.49	9.7
May 1-24	18.8	4.4	1.39	5.79	8.28	32.1
May 24-29	14.4	.5	1.38	1.88	10.16	36.8
May 29-June 5	13.9	3.4	.86	4.26	14.42	55.9
June 5-12	10.5	6.2	.50	6.70	21.12	81.8
June 12	4.0					
Seasonal total[1]				25.76		100.0
DEADHORSE CREEK, 1969:						
Total watershed						
April 9-22	13.7	1.4	.8	2.2	2.2	11.2
April 23-29	12.3	1.5	.8	2.3	4.5	23.0
April 30-May 6	10.8	1.6	1.8	3.4	7.9	40.3
May 7-13	9.2	.2	.1	.3	8.2	41.8
May 14-20	9.0	1.5	1.0	2.5	10.7	54.6
May 21-27	7.5	4.8	.3	5.1	15.8	80.6
May 28-June 3	2.7	1.7	.2	1.9	17.7	90.3
June 4-10	1.0	1.0	.9	1.9	19.6	100.0
June 11	0					
Upper basin[2]						
April 9-22	15.3	1.1	.8	1.9	1.9	4.7
April 23-29	14.2	1.1	.8	1.9	3.8	17.9
April 30-May 6	13.1	1.5	1.8	3.3	7.1	33.5
May 7-13	11.6	0	.1	.1	7.2	34.0
May 14-20	11.6	1.0	1.0	2.0	9.2	43.4
May 21-27	10.6	6.0	.3	6.3	15.5	73.1
May 28-June 3	4.6	2.6	.2	2.8	18.3	86.3
June 4-10	2.0	2.0	.9	2.9	21.2	100.0
June 11	0					
Lower basin						
April 9-22	11.9	1.8	.8	2.6	2.6	14.6
April 23-29	10.1	1.9	.8	2.7	5.3	29.8
April 30-May 6	8.2	1.8	1.8	3.6	8.9	50.0
May 7-13	6.4	.7	.1	.8	9.7	54.5
May 14-20	5.7	1.7	1.0	2.7	12.4	69.7
May 21-27	4.0	3.4	.3	3.7	16.1	90.4
May 28-June 3	.6	.6	.2	.8	16.9	94.9
June 4-10	0		.9	.9	17.8	100.0
June 11	0					

[1]As derived from table 1.
[2]Data collected from upper basin were identical with those from Lexen Creek.

peaked much earlier than on the opposite north slope. It should be noted, however, that the time lag between maximum snowmelt rates on the north and south slopes diminished with increasing elevation. This effect is also seen in our study—dispersion of areal snowpack depletion rates around the watershed mean on high-elevation Lexen Creek is considerably less than on Deadhorse Creek. Gary and Coltharp (1967) similarly observed that snowmelt rates were about the same on high-elevation north and south slopes in northern New Mexico. Areal melt on Deadhorse Creek corrected for precipitation after peak water equivalent is summarized in table 5.

Relative Water Yields from Upper and Lower Deadhorse Creek

Streamflow from Lexen Creek can vary from 60 percent of Deadhorse in high runoff years to almost 90 percent in low runoff years (table 6). Because this variation has important implications for watershed management, water yields were compared further.

Table 6.--Relative seasonal water yields from Deadhorse and Lexen watersheds, 1956-69

Year	Generated runoff[1]		Ratio of runoff, Lexen:Deadhorse
	Deadhorse Creek	Lexen Creek	
	- - Acre-feet - -		Percent
1956	647.8	397.0	61
1957	1041.9	623.9	60
1958	688.8	424.6	62
1959	533.4	345.8	65
1960	595.2	384.0	64
1961	269.3	233.0	87
1962	943.9	580.0	61
1963	139.7	120.5	86
1964	339.5	275.4	82
1965	628.3	383.0	61
1966	213.3	186.7	88
1967	463.0	329.3	71
1968	439.1	328.9	75
1969	428.0	297.5	69
Mean			70

[1]Above an assumed constant baseflow of 0.2 and 0.1 cubic foot per second on Deadhorse and Lexen Creeks, respectively.

Deadhorse and Lexen watersheds are contiguous and physiographically similar. Early spring snow surveys have shown that snow accumulation on Lexen is similar to that observed in the high elevations of Deadhorse. Moreover, the rate of snow-cover depletion in the higher elevations of Deadhorse Creek is identical to that of Lexen Creek (figs. 9, 10).

In this analysis, it was assumed that flows generated from Lexen Creek correspond to like volumes from Deadhorse Creek above 9,850 feet (the elevation of Lexen Creek stream gage). On Deadhorse watershed, the apparent drainage area above this elevation is 356 acres or 53.3 percent of the watershed total. Relative contributions of snowmelt runoff from upper and lower Deadhorse Creek are summarized for several intervals during the 1969 snowmelt runoff season in table 7. Data

Table 7.--Relative contributions to streamflow from upper and lower basins of Deadhorse Creek during the 1969 snowmelt runoff season

Interval 1969	Runoff generated during interval		
	Deadhorse Creek	Upper Deadhorse[1]	Lower Deadhorse[2]
	- - - - - - Inches - - - - - -		
April 20-May 21	3.6	5.4	1.6
May 21-May 28	2.7	3.9	1.3
May 28-June 4	.5	.6	.4
June 4-June 11	.9	1.5	.2
Total	7.7	11.4	3.5

[1]Measurements taken on Lexen Creek were transposed to upper Deadhorse Creek since assumption is that flows generated from Lexen Creek are comparable. Upper Deadhorse Creek (above 9,850 feet) has an estimated drainage area of 356 acres or 53.3 percent of the watershed total.

[2]Lower Deadhorse Creek has an estimated drainage area of 311 acres or 46.7 percent of the watershed total.

in the summary were obtained by the expression

$$D = 0.53L + 0.47 D_L \text{ or}$$

$$D_L = \frac{D - 0.53L}{0.47}$$

where

D_L = the generated flow from lower Deadhorse Creek (inches)

D = the generated flow from the entire Deadhorse Creek watershed (inches)

L = the flow generated from Lexen Creek (inches)

As expected, resultant streamflow from snowmelt on lower Deadhorse Creek was less than 30 percent of that generated from the upper basin, even though total precipitation below 9,850 feet was about 80 percent of the high-elevation input (see table 4). Relative water yields from the upper and lower basins for each year of record (summarized in table 8) are plotted in figure 13. Low-elevation water yields apparently can vary from near zero for poor runoff years to a maximum during good years of about 50 percent of the flow generated from the upper basin.

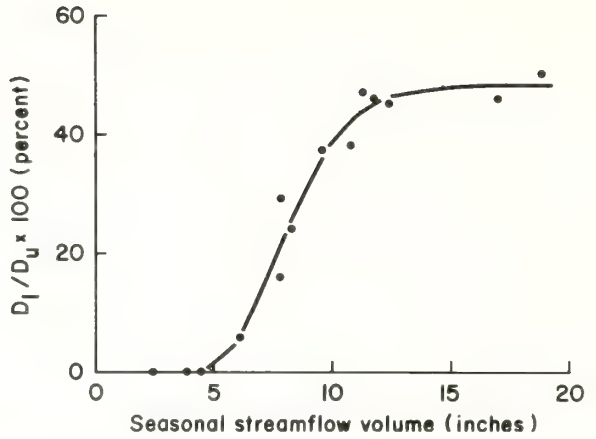

Figure 13.--Contribution of snowmelt runoff from lower Deadhorse (expressed as a percentage of that from upper Deadhorse) as a function of seasonal streamflow from the entire watershed.

Table 8.--Relative seasonal contributions of snowmelt runoff from upper and lower Deadhorse Creek

Year	Generated runoff			Ratio of runoff, Lower:Upper
	Dead-horse Creek	Upper Dead-horse[1]	Lower Dead-horse	
	- - - -	Inches	- - - -	Percent
1956	11.7	15.6	7.2	46
1957	18.8	24.5	12.3	50
1958	12.4	16.7	7.5	45
1959	9.6	13.6	5.0	37
1960	10.7	15.1	5.7	38
1961	4.8	9.1	(-0.1)	0
1962	17.0	22.8	10.4	46
1963	2.5	4.7	0	0
1964	6.1	10.8	.7	6
1965	11.3	15.0	7.1	47
1966	3.8	7.3	(-0.2)	0
1967	8.3	12.9	3.1	24
1968	7.9	12.9	2.1	16
1969	7.7	11.4	3.5	31
Mean	9.5	13.7	4.7	34

[1]Measurements taken on Lexen Creek were transposed to upper Deadhorse Creek since assumption is that flows generated from Lexen are comparable.

Water Balance

Watershed efficiency (generated runoff expressed as a percentage of snowmelt input) averaged 48 percent during the 1952 runoff season on Fool Creek (fig. 14). This compares with an average 39 percent for the period 1943-54 (table 9). In 1952, snowmelt averaged 2.9 inches before any streamflow was generated. Between May 1 and May 29, 37 percent of the input was yielded as streamflow. During highest streamflow, efficiency averaged 73 percent, then decreased markedly until the end of snowmelt. It should be noted that more than 90 percent of the seasonal runoff volume was generated before 50 percent of the watershed became bare of snow. This is considerably more than previously reported on Beaver Creek in Arizona by Ffolliott and Hansen (1968). During highest streamflow on Fool Creek (May 29-June 12), areal snow cover decreased from 90 to 55 percent. Streamflow produced during this time interval comprised 70 percent of the seasonal volume. After the peak, the residual snowpack which covered 45 percent of Fool Creek produced only 13 percent of the seasonal runoff.

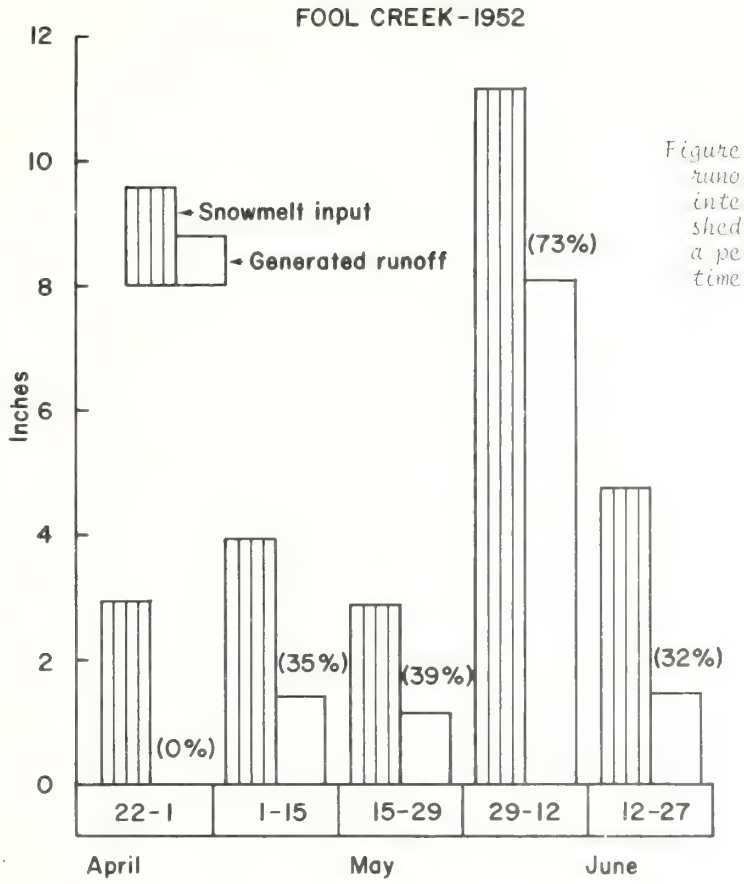

Figure 14.--Comparison of snowmelt and generated runoff from Fool Creek for five snow survey intervals during the 1952 melt season. Watershed efficiency (generated runoff expressed as a percentage of snowmelt input) during each time interval is shown in parentheses.

Table 9.--Fool Creek water balance for 1943-54 record period

Year	Peak water equivalent	Subsequent precipitation	Total[1]	Generated runoff[2]	Efficiency[3]
	Inches				Percent
1943	17.4	7.8	25.2	9.8	38.9
1944	13.9	9.3	23.2	6.3	27.2
1945	--	--	--	--	--
1946	11.5	4.3	15.8	7.4	46.8
1947	16.2	9.4	25.6	11.0	43.0
1948	13.9	5.0	18.9	7.8	41.3
1949	14.0	7.2	21.2	7.9	37.3
1950	14.1	6.4	20.5	7.6	37.1
1951	18.4	6.6	25.0	10.7	42.8
1952	19.4	5.6	25.0	12.0	48.0
1953	11.4	8.2	19.6	7.9	40.3
1954	9.1	3.9	13.0	2.4	18.5
Mean	14.5	6.7	21.2	8.2	38.7

[1]Index of total precipitation input determined from the figure-eight snowcourse which traverses the watershed.
[2]Above an assumed constant baseflow of 0.3 cubic foot per second.
[3]Generated runoff expressed as a percentage of snowmelt input.

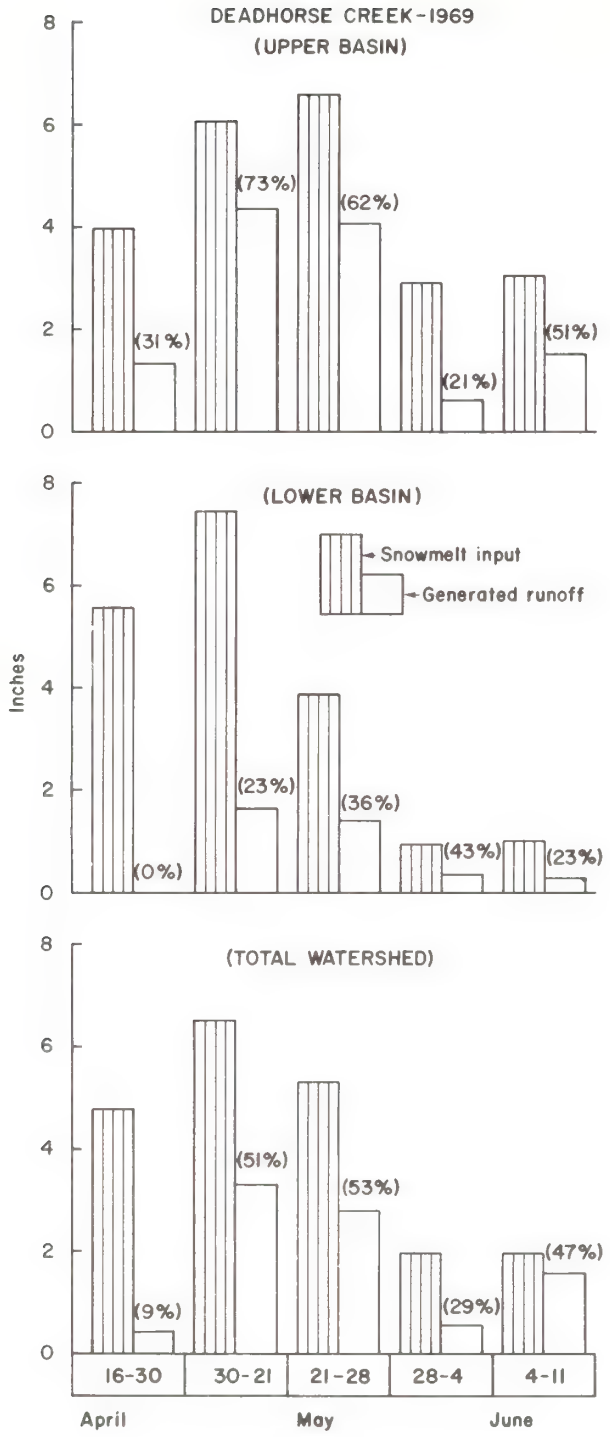

Figure 15. - Comparison of snowmelt and generated runoff from Deadhorse Creek for five snow-survey intervals during the 1969 melt season. Watershed efficiency (generated runoff expressed a percentage of snowmelt input) during each time interval is shown in parentheses.

Deadhorse watershed averaged 39 percent efficiency; the upper basin averaged 54 percent, while the lower basin averaged only 20 percent (fig. 15). Less than 15 percent of the snowmelt prior to May 21 in the lower basin was converted to streamflow compared with 59 percent in the upper basin. On May 21, snow cover in the upper basin occupied approximately 90 percent of the area, whereas in the lower basin, more than half the area was bare. Snow cover was complete on the north slopes in both the upper and lower basins at this time. After May 21, streamflow accounted for 1.9 inches of the estimated 3.5 inches generated from the lower basin. Precipitation input was 5.4 inches. It is important to note that, in the upper basin, almost 90 percent of the seasonal runoff volume was generated before 60 percent of the area became bare of snow. Furthermore, more than 80 percent of the upper basin was still covered with snow when seasonal snowmelt rates reached their peak.

The high efficiencies on Lexen Creek (and similarly, upper Deadhorse) and Fool Creek are apparently the result of (1) almost complete snow cover at the time when seasonal snowmelt rates are maximum on all aspects, (2) a delayed and short snow-cover depletion season, and (3) relatively low recharge and evapotranspiration losses.

Snow-Cover Depletion in Relation to Runoff and Melt

Snowpack depletion is plotted as a function of accumulated melt (ablation) and observed and generated runoff in figure 16 for the period 1964-68. Each watershed has a characteristic relationship between snowpack depletion and runoff that apparently does not change appreciably, even though the amount of snowpack and weather conditions which produce runoff each year vary considerably. It is possible that the scatter around the mean curves is the result of annual differences in initial snowpack water equivalent, recharge requirements, and meteorological conditions during snowmelt. However, experimental error may account for a large portion of the variation.

The relationships derived for Lexen (upper Deadhorse) resemble those of Fool Creek (before harvest cutting) due to their similar snow-cover depletion, snowmelt, and losses. The closer agreement be-

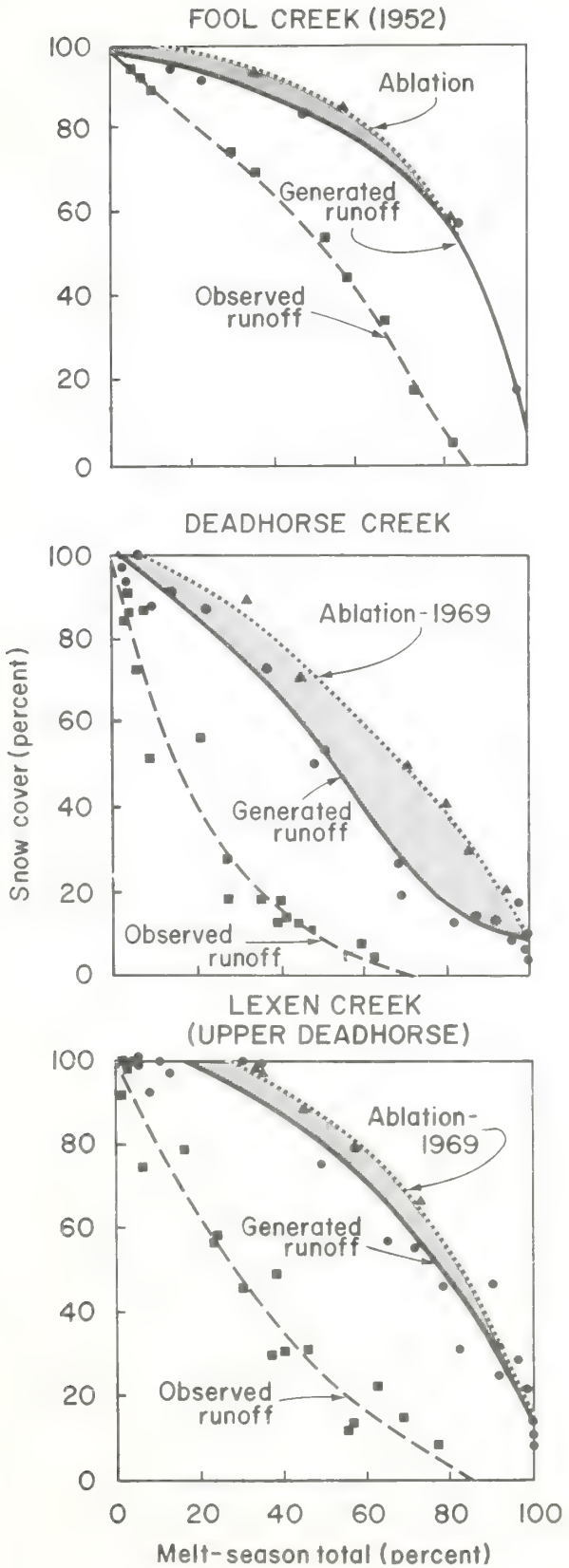

Figure 16.--Snow-cover depletion in relation to runoff and ablation for Fool Creek, Deadhorse, and Lexen (upper Deadhorse) Creek watersheds.

tween the ablation and generated runoff relationships on Fool Creek and Lexen (upper Deadhorse) reflects accelerated depletion of the snow cover after most of the snowpack water equivalent has melted. This provides for more efficient conversion of snowmelt runoff to streamflow.

On Deadhorse Creek, the large differences in snowmelt rates and high recharge and evapotranspiration losses in the lower basin (see figs. 12, 15) are reflected by the conspicuous displacement between the generated runoff and ablation curves. When the area of snow cover decreases rapidly with increasing ablation and runoff, as in the lower basin of Deadhorse watershed, less efficient conversion of snowmelt to streamflow is indicated.

Summary

Snowmelt and resultant snowpack depletion and water yield were studied on three experimental watersheds in the Fraser Experimental Forest. Drainage areas within the following three physiographic complexes were analyzed: (1) forested, with generally east- and west-facing aspects between 9,600 and 11,500 feet (Fool Creek); (2) forested, with predominantly north- and south-facing aspects between 9,450 and 9,850 feet (lower Deadhorse Creek); and (3) forested, with primarily north and south aspects, but with the drainage area between 9,850 and 11,600 feet (Lexen and upper Deadhorse Creeks). Deadhorse and Lexen watersheds are contiguous. The analyses were based primarily on data collected in 1952 from Fool Creek, and in 1969 from Deadhorse and Lexen watersheds.

On Deadhorse Creek, the snowpack depletion season was relatively long, and depletion rates varied widely on subunits within the watershed. In contrast, on Fool Creek and Lexen, depletion of the snow cover was delayed for some time after the runoff season began, and large areas then became bare of snow simultaneously.

Seasonal snowmelt was essentially the same on the generally east and west aspects of Fool Creek at all elevations. On Deadhorse Creek, snowmelt rates differed greatly between the low-elevation north and south slopes, but the lag between them diminished with elevation.

Relative water yields from the drainage areas above and below 9,850 feet on Deadhorse Creek were estimated by weighted differences between streamflow measured on adjacent Lexen Creek watershed and the total flow of Deadhorse. In 1969, streamflow from snowmelt in the lower basin of Deadhorse was less than 30 percent of that generated from the upper basin, although precipitation input was about 80 percent of the high-elevation input. Fourteen years of streamflow data indicate that water yields from the lower basin can vary from near zero for poor runoff years to a maximum during good years of about 50 percent of the flow generated from the upper basin.

In 1952, efficiency (water yield expressed as a percentage of snowmelt input) averaged 48 percent on Fool Creek, compared to an average 39 percent for an 11-year record period. Efficiency was low when snowmelt runoff first began, and also later in the season when snow became patchy at the higher elevations. Conversion of snowmelt into water yield was highest when streamflow was at its peak. More than 90 percent of the seasonal runoff volume was generated before 50 percent of the watershed was bare of snow. During the period of highest streamflow, areal snow cover decreased only 35 percent and produced 70 percent of the seasonal water yield.

In 1969, overall efficiency on Deadhorse Creek averaged 39 percent; the upper basin averaged 54 percent and the lower basin 20 percent. The upper basin generated almost 90 percent of the seasonal runoff volume before 60 percent of the area became bare of snow.

Comparisons of the water balance and snow-cover depletion on Lexen Creek, upper Deadhorse, and Fool Creek revealed hydrologic similarities among the watersheds in spite of obvious physiographic dissimilarities. These similarities included: (1) almost complete snow cover when seasonal snowmelt rates on all major aspects of the watersheds were maximum; (2) a delayed and short snow-cover depletion season; and (3) relatively low recharge and evapotranspiration losses.

Conclusions

These results are at best crude indices of the energies and physiographic features affecting the disposition of snowmelt runoff. The greatest shortcoming of the study is the questionable accuracy of the areal estimates of precipitation input. The watershed transposition technique employed to determine relative water yields from Deadhorse Creek is also open to criticism. The assumption that upper Deadhorse and Lexen Creeks yield like quantities of streamflow should be verified by field measurements.

Nevertheless, some useful indications have been derived which are pertinent to a better understanding of the hydrology of subalpine watersheds. For example, it appears that in the high water-yielding snow zone, the hydrologic regimes of subunits within even small forested watersheds can vary by several orders of magnitude. Quantitative information of this nature is necessary for determining the potentials on these watersheds for water yield improvement through harvest cutting and/or weather modification.

Because areal snow cover, like streamflow, is an integral measurement, it can be effectively utilized in the identification of watersheds and subunits within watersheds which contribute most (or least) efficiently to streamflow. Also, the index relationships between snowpack depletion and resultant ablation and streamflow derived for experimental watersheds can be effectively used in predicting the hydrology of other areas in the subalpine zone.

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Areal snow-cover depletion and resultant snowmelt and water yield were studied on three small watersheds in the Fraser Experimental Forest.

High water yield efficiencies were observed on two watersheds which had: (1) almost complete snow cover when seasonal snowmelt rates on all major aspects were maximum; (2) a delayed and short snow-cover depletion season; and (3) moderate recharge and evapotranspiration losses.

Water yield efficiency in one watershed with low-elevation south slopes was least. In 1969, streamflow from the drainage area on this basin below 9,850 feet was less than 30 percent of that generated from above this elevation. Fourteen years of comparative streamflow indicated that water yields from the low-elevation subdrainage can vary from near zero in poor runoff years to a maximum during good years of about 50 percent of the flow generated from the high-elevation subdrainage.

Key words: Aerial photography, runoff, snow surveys, stream gaging, hydrologic cycle.

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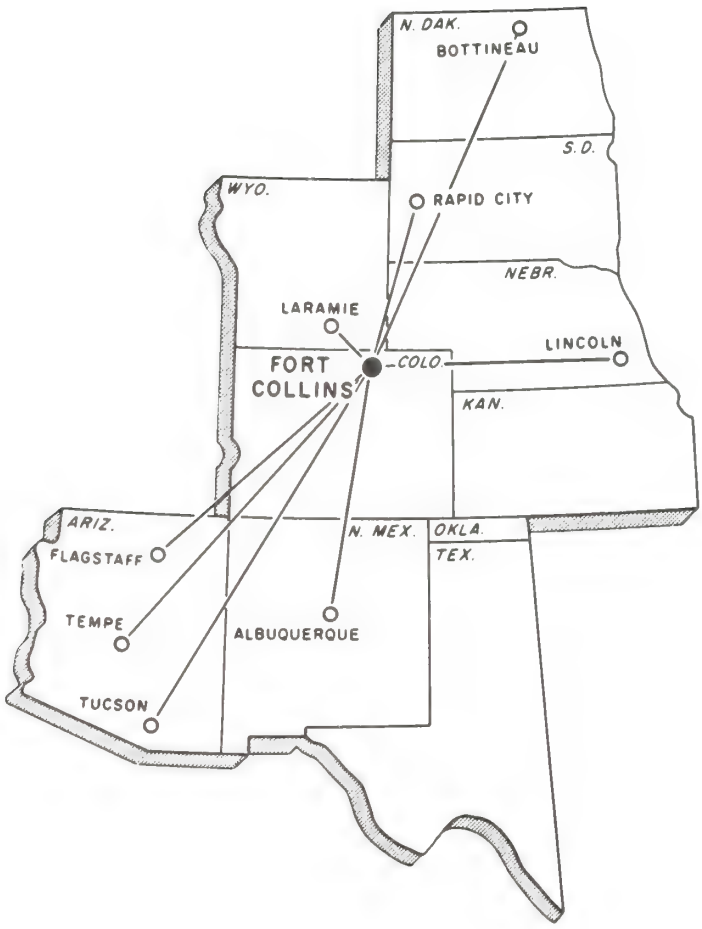
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ichard s. driscoll

color aerial photography

a new view for range management

USDA FOREST SERVICE
RESEARCH PAPER RM-67
MARCH 1971

ABSTRACT

Shrubs such as antelope bitterbrush, big sagebrush, snowberry, and true mountainmahogany can be identified more consistently on large-scale (1:600-1:1,200) color infrared aerial photographs than on the same scale color aerial photographs. Identification of relatively large forbs, including Fremont geranium and orange sneezeweed, is also easier on large scale color infrared. Neither film type appeared to give improved information regarding site delineation on smaller scale photographs. Other features of the range environment, including rodent disturbances, can best be identified on color infrared at photo scales up to 1:2,400. All of this depends on obtaining photographs at the right time of year in respect to phenology of the vegetation.

KEY WORDS: Aerial photography, infrared color photography, color photography, indicator plants, forest surveys, range surveys, land classification, forage plants, phenology.

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Research Paper RM-67

March 1971

COLOR AERIAL PHOTOGRAPHY--

A New View for Range Management

by

Richard S. Driscoll

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Rocky Mountain Forest and Range Experiment Station[1]

[1]Central headquarters maintained at Fort Collins in cooperation with Colorado State University. Trade names and commercial products are mentioned for the benefit of the reader and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.

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New and improved color aerial films, coupled with high-speed aerial cameras, enable us to identify individual plant species as well as other features of the range environment. These photo systems, linked with potential automated photo interpretation techniques guided by ground sampling, provide possibilities for updating range inventories at less cost than conventional ground surveys alone. Imaged below on a 1:2,400 scale color infrared photograph are blocks of native range 75 feet square, treated with herbicide (s), fertilizer (f), a combination of herbicide and fertilizer (b), and neither (n). The herbicide/fertilizer treatments induce a nonnormal physiological effect which should provide clues to detection of stressed vegetation.

Color Aerial Photography--
A New View for Range Management

Richard S. Driscoll

Black-and-white panchromatic aerial photographs were first documented as an integral part of range inventory procedures in 1937 (U. S. Inter-Agency Range Survey Committee 1937). In an appraisal of range survey methods, aerial photography was recommended over other methods to provide more accurate vegetation type maps and to obtain more dependable forage estimates (Reid and Pickford 1942).

The application of a sampling procedure for range inventories based on aerial photography has been described by Harris (1951). Lord and McLean (1969) discussed how some characteristic aerial-photo patterns of vegetation and land forms were used in soils survey and land classification.

Primarily, black-and-white aerial photography has been used for mapping broad vegetation types—such as grassland versus shrubland versus timberland—and to locate cultural features including roads, fences, seeded areas, or special situations such as rodent infestations. The photographs were usually of medium scale (1:15,840 to 1:30,000) and of average quality on 9-inch by 9-inch format. In addition, photographs available for use had most likely been taken during some previous year. Consequently, image characteristics observed represented current ground conditions only in a gross fashion such as the apparent boundary between generalized vegetation types.

For the above reasons, and because of the experiences of foresters with color aerial photography (Sayn-Wittgenstein 1960, 1961; Heller et al. 1964, 1967; Aldrich 1966), research was started at the Rocky Mountain Forest and Range Experiment Station in 1967 on the feasibility of large-scale (1:600 to 1:4,600), 70 mm (2¼-inch by 2¼-inch format) color aerial photography flown at different times during the growing season for detecting and identifying plant species, communities, and other habitat features in different range environments in Colorado. This Paper reports some early findings at the Rocky Mountain Station. Carneggie and Reppert (1969) have reported on use of this kind of photography for northeastern California grasslands and shrublands.

The Study

Test Sites

Four test sites representing contrasting vegetation types were selected for this research.

Black Mesa is located approximately 30 airline miles west of Gunnison, Colorado, on a spruce-fir/grassland cattle summer range at an elevation of approximately 9,800 feet. It is also grazed by deer and elk from spring through fall. Thurber fescue, Idaho fescue, aspen fleabane, and Fremont geranium are the most common herbaceous species in the grassland areas.[2/]

Manitou is located approximately 25 airline miles northwest of Colorado Springs, Colorado, on a ponderosa pine/bunchgrass cattle summer range. Deer use the area yearlong. The specific study location occurs in a parklike opening at about 7,700 feet elevation. Blue grama, Arizona fescue, pussytoes, and fringed sagebrush are the most abundant species on this test site.

Kremmling is located on a deer winter range approximately 10 airline miles northeast of Kremmling in north-central Colorado in a mixed-shrub type. Cattle graze this area lightly at various times from spring through fall. The site is in a very broad mountain valley, locally known as Middle Park, at an elevation of about 8,000 feet. Big sagebrush, alkali sagebrush, antelope bitterbrush, snowberry, rabbitbrush, and broom snakeweed are the most abundant shrubs.

McCoy is located approximately 25 airline miles southwest of Kremmling, Colorado, in the pinyon-juniper type. It is used by livestock most of the year, and is an important deer winter range. The site is within a complex, rolling to hilly topographic pattern of the upper Colorado River drainage at an elevation of approximately 7,400 feet. Pinyon pine and Rocky Mountain juniper provide the general aspect to the area. True mountainmahogany and big sagebrush are common understory species; herbaceous species are relatively minor.

2/ Common and botanical names of plants mentioned are given inside back cover.

Aerial Photography

Flight lines from 250 feet to 4,500 feet long were established and marked on the test locations to assure photographic coverage of specific kinds of plants, plant communities, and other items in the range environment. These items were marked on the ground, usually with wood surveyor stakes or some arrangement of wood lath so they could be detected and positively identified in the aerial photographs (Francis 1970).

Dual 70 mm format aerial cameras were mounted in a Forest Service-owned Aero Commander 500 B aircraft to obtain simultaneous imagery with two different film types. Photo scales ranged from 1:600 to 1:4,600.

The 70 mm camera systems used for this work have several significant advantages over conventional aerial camera systems. The 70 mm systems have fast shutter speeds and rapid pulse rates which, when coupled with high-speed small-format film, make possible low-level airplane photography of high resolution for stereo viewing. Other advantages include relatively low cost, small size and light weight, and variable lenses interchangeable in flight.

The film types were Anscochrome D-200, type 7230, exposed with a Wratten 1-A skylight filter, and Kodak Ektachrome Infrared Aero, type 8443, exposed with a Wratten 12 filter. These color film types were selected for two reasons: (1) the greater possibility of identifying individual items in color rather than in black and white, and (2) the ability of color infrared film to portray, in discriminate color images, differences among subjects in their reflectance of near-infrared radiation not observable to the unaided eye.

Anscochrome D-200 is an ordinary color reversal aerial film constructed with a three-layer emulsion sensitized to red, green, and blue light. When exposed and processed properly, the activated dyes form color images that closely match the color of the objects photographed.

The infrared color film is a false-color, reversal film. It differs from ordinary color film in that the three sensitized layers are sensitive to green, red, and near-infrared radiation, instead of the usual blue, green, and red. Since all three layers are also sensitive to blue light, we used a yellow Wratten 12 filter to absorb that part of the spectrum. When exposed and processed properly, this combination of sensitizations and dyes produces false colors for most natural objects. For example, rapidly growing green vegetation produces an image in shades of magenta or red because of relatively strong near-infrared reflectance. Bare soil or mature, drying vegetation appears as shades of cyan or blue because of little near-infrared reflectance. Heller (1970) describes in more detail the light/film physics involved when using this film type.

All film was processed to color transparencies to avoid potential loss of resolution and color balance which often occur when the film is processed to prints.[3/]

Photo missions were flown over the test sites when (1) the growing season was starting, (2) the growing season was at its peak, (3) the most abundant species were starting dormancy, and (4) most species were dormant, but prior to snowfall. In addition, the overflights of the Manitou test site were planned to provide before-and-after photos of native range treated with herbicides and fertilizers. This selection of photo missions was planned because no single time period could be expected to provide optimal data about the many items in the complex range environment.

Some Interpretive Comparisons of the Film Types

The identification of an object in an aerial photograph must be based on characteristics of the object as imaged by the camera and film, not by the usual characteristics of the object as viewed firsthand. The photo-image characteristics used for identifying specific items include color, pattern, texture, relative size, shape, and shadow.

Plant Identification

Phenology, or the stage of plant development, is an important consideration when attempting to identify individual plant species in aerial photos.

[3/] *All photography was procured and film developed cooperatively with the Forest Remote Sensing Project, Pacific Southwest Forest and Range Exp. Sta., USDA Forest Serv., Berkeley, Calif.*

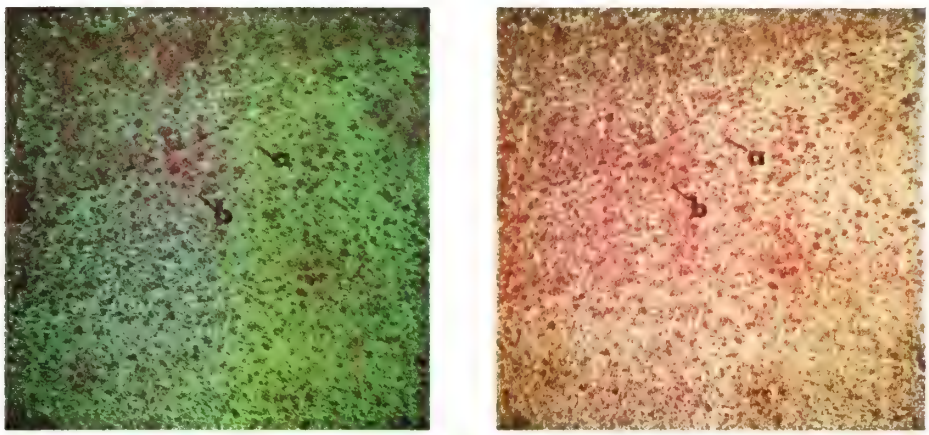


FIGURE 1. Quercus sp. leaves from Kobe (left) and Kawachinagano (right) covered sporadically August 21, 1967, under 1.5% gold solution (a) and shown successively as they appeared to the eye and on the false-color infrared photographs. The two species are difficult to distinguish in the color photo.

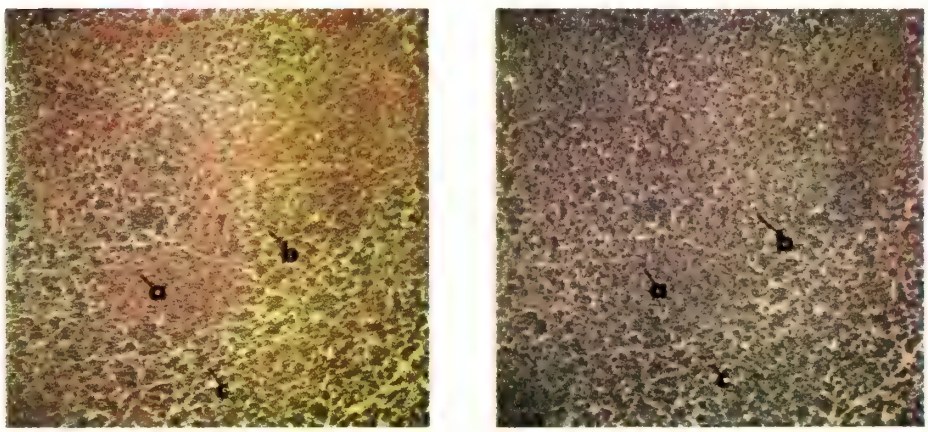
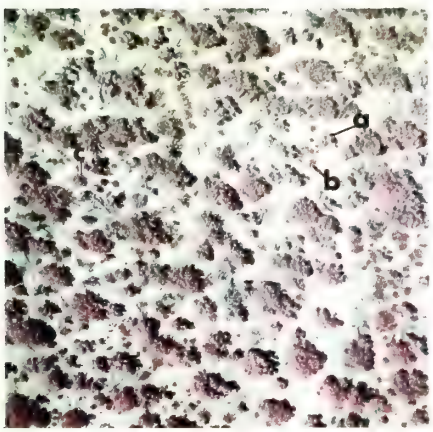


FIGURE 2. Buttercup (a), bird's-foot trefoil (b), and speedwell (c) are more easily detected and identified in the infrared (right) as compared to normal photography (left) at a scale of 1:1,000 mapped on 1 km. Automated pattern-recognition techniques which discriminate between green versus yellow-green could be used to determine the amount (area or numbers) of these species in pastures.



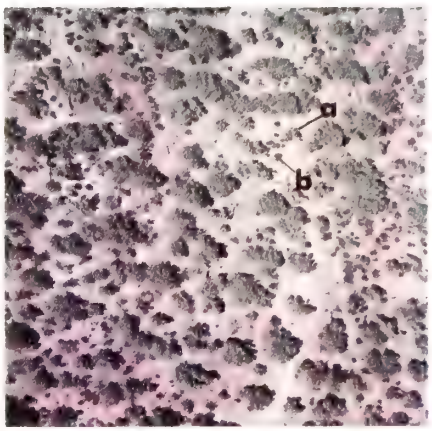
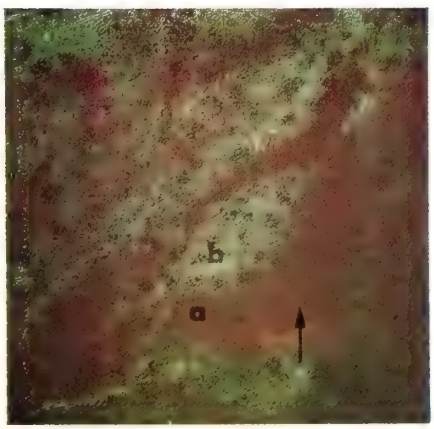


Figure 5. The limited amount of detectable difference between healthy and diseased pine (a) as possible on the color infrared photo (left) at 1:1,500 scale, compared to that in August. These species are frequently misinterpreted on color photos taken at the same scale.



infrared photograph exposed in mid-Sep-

For example, mid-July photographs of the Black Mesa site showed the vegetation a constant shade of green on normal color film, and a constant shade of red on color infrared. At this date, all herbaceous plants were growing vigorously with colors (National Bureau of Standards ISCC-NBS system of color designations) between 125 (medium olive green) and 122 (grayish yellow green). These color differences were so subtle they could not be distinguished in the aerial photographs, regardless of photo scale or film type. Because of phenological changes by mid-August, however, individual species could then be differentiated in aerial photographs, primarily on the basis of color. The plant species were in different growth stages, foliage colors were changing, and these differences were detectable in 1:750 scale aerial photographs. For example, the visual ground color of geranium foliage was 16 (dark red). The resultant 69 (deep orange yellow) color imaged on the color infrared photographs provided easy detection and positive identification of the species (fig. 1) since no other species had this color. The population density could thus be accurately determined if this were an objective of a resource inventory. On the color photographs at the same scale and date, the species could be detected and identified only by careful searching under 4x stereo-magnification.

Other relationships were found for identifying shrubs from the aerial photos of the Kremmling test site flown in mid-July. Apparent height and stem leafiness were the important image characteristics, in addition to color, for discriminating between bitterbrush and snowberry. Bitterbrush plants were taller and leaf arrangements on the stems were more vertical and less dense than snowberry. The height difference, which provided a shadow difference, was discernible on 1:1,000 scale photographs under 4x stereo, and the difference in leaf arrangements provided a more discrete image texture for snowberry. With these characteristics, the two species could be distinguished on both film types.

Actual colors of these two species in mid-July were very similar, 127 (grayish olive green) and 125 (medium olive green), respectively. However, image colors in photos taken at that time provided discriminatory differences between the two species, especially in the color infrared. In these photos, bitterbrush was usually 15 (medium red) while snowberry was generally a 13 (deep) to 16 (dark red). On the color photos, bitterbrush was usually 125 (medium olive green) and snowberry 150 (grayish green). The color differences between these species, apparently caused by leaf size and arrangement on the stems, were more obvious in the color infrared photographs.

Image differences between bitterbrush and big sagebrush at the Kremmling site were sufficiently discrete on mid-July photos at 1:1,000 scale that they could be distinguished on both film types. However, the difference between 15 (medium red) of bitterbrush versus the 240 (light reddish purple) of big sagebrush was more apparent in the color infrared photographs than were the green color differences between the two species in the color photograph (fig. 2).

Mountainmahogany, pinyon pine, and juniper could be discriminated well on 1:1,200 scale color infrared photographs on the McCoy site taken August 3, 1968 (fig. 3). Although apparent ground colors of the foliage of mountainmahogany and pine were the same, 125 (medium olive green), the relatively large, shiny, thick-cuticled leaves of mountainmahogany apparently reflected more infrared than the pine needles. This caused an 11 (very red) to a 13 (deep red) image for mountainmahogany and a 43 (medium reddish brown) image for the pine. Because of relative height differences, mature specimens of the two plants could be differentiated on both film types, but identification errors would be frequent when attempting to differentiate mature mountainmahogany and small pines in the same size range on the color photographs.

Fringed sagebrush is usually classed as an undesirable livestock forage. Surveillance of population changes of the species would be important in evaluating range trend or for potential plant control projects. In 1:600 scale color infrared photographs taken June 1, 1968 at the Manitou test site, the species imaged 12 (slightly red) to 11 (very red), and was easily differentiated from other items in the area. At this time, few other plant species had initiated growth and consequently produced minimal infrared reflectance. Fringed sagebrush could be detected and identified in the color photographs, but image character differences were not as unique as in the color infrared film.

Site and Treatment Classification

Site distinction is an important facet of any range management program involving measurement and interpretation of vegetation. With aerial photographs, sites can be better differentiated if vegetation is used as an indicator. The synoptic view of an area afforded by an aerial photograph is much superior to the limited low-angle oblique view seen from the ground.

Given good quality black and white panchromatic aerial photographs of the usual scale (1:20,000), a careful interpreter can discriminate among most sites on the basis of image texture and gray tone. The addition of color introduces another dimension which should decrease interpretation errors and increase the accuracy of discrimination among sites. There was no apparent advantage favoring one or the other of the color photographs for this purpose. On 1:4,600 scale photographs, however, site delineations may be more accurate and the possibility of identifying individual plants may be increased by using color infrared (fig. 4).

At Manitou, the test site included an investigation of various fertilizer, herbicide, and grazing treatments on vegetation. Blocks of land 75 feet square were used for the treatments. Color differences between treatments could be distinguished in 1:2,700 color infrared photographs taken in August, 2 months after treatments were applied (see page one). Comparisons with normal color film were not possible because camera malfunctions resulted in atypical photographs. The facts that differences among treatments could be discriminated in the color infrared photos, and that individual species could be identified in larger scale photographs of the same type, suggest treatment effects might be assessed directly from aerial photographs. Ground conditions at an instant in time could be recorded on film and later analyzed in the office, which would alleviate the perpetual problem of time-dependent field measurements confounded by seasonal changes in the vegetation.

Other Habitat Features

Rodents are often harmful to rangelands, especially when population densities are high. For example, average populations of northern pocket gophers (22 per acre) in the vicinity of the Black Mesa site have been estimated to consume nearly 300 pounds of air-dry herbage per acre each year (Colorado Cooperative Pocket Gopher Project 1960). During expected population increases, common on the test site, these rodents would consume a significant amount of the total herbage production.

Gopher casts and mounds were easily detected on the 1:600 scale photos of the Black Mesa test site. The casts, "ropes" of soil deposited on the ground surface after spring snowmelt, were most easily identified in early June photographs. Fresh mounds, most conspicuous in late summer to early fall when young-of-the-year are establishing independent burrow systems, were easily identified in photos taken October 1, 1968. They seemed more apparent in the color infrared film, since some images of plants in the regular color photographs appeared similar to the mound images (fig. 5). The vegetation at that time of year still reflected sufficient infrared that it registered pink in the infrared film, compared with the brownish image color of the mounds. Since pocket gopher mounding is closely related to population dynamics (Reid et al. 1966), this type of photography could be used to monitor population changes on a broader basis than ground surveys. Relative amounts of mounding activity were also identifiable in 1:2,400 scale photographs.

Many other items in the range environment were identifiable in the photographs. Ant mounds 12 inches in diameter appeared cone shaped, different from irregularly shaped gopher mounds, in 1:1,000 scale photos. Surface entrances to burrow systems of ground squirrels at the Manitou test site were identifiable in 1:600 scale photographs. Continuous herbaceous litter cover and dead shrub crowns were generally easier to detect on the color infrared photos, due primarily to the light gray image color.

Deer carcasses at the Kremmling site were identifiable in both film types at scales up to 1:4,000 regardless of when, during the growing season, the photographs were taken. They were more obvious on the color infrared compared to color photos because of greater contrast between (1) the reddish-imaged vegetation and the nearly white-imaged carcass versus (2) greenish-imaged vegetation and

the light yellowish-brown-imaged carcass. In addition, carcasses of the current year could be distinguished from carcasses of the previous year on color infrared photographs taken in late spring or early summer. Decay of the carcass over a year coupled with winter-spring moisture apparently fertilized plants immediately adjacent to the carcass. This enhanced the infrared reflectance of the vegetation, and resulted in a bright red halo around the year-old carcass, a phenomenon not found with a fresh carcass. Thus, large-scale color infrared photography may be feasible for sampling current winter deer mortality.

Projections

Color aerial photography adds a new view to measurement and interpretation of range vegetation. Interpretation of color infrared photos appears to offer most promise for detection and identification of individual plants. Neither film type shows a definite advantage over the other for discriminating among sites or vegetation types.

Successful interpretation of aerial color photos depends on season of year the photos were taken, which is related to phenology, size of the plant, associated vegetation, and denseness of the stand. Time of day (sun angle) and growth-habit variations among species also affect image characteristics, and need additional investigation. Equally important is the fact that there is no one optimum time during the growing season to procure photography for interpretation of the many items in the complex range environment. The selection of a time or times for photo missions depends on the objective of a job. For example, if the object is to monitor population changes of geranium on Black Mesa, mid-August photography is satisfactory. If the object is to determine the degree, extent, or changes in pocket gopher activities, however, aerial photographs should be taken in late summer or early fall.

The 70-mm photographic system used for this study must be considered a sampling tool. The camera system was developed primarily to take photographs from low-flying aircraft. Due to the relatively small film format, 70-mm by 70-mm (2¼-inch by 2¼-inch), and the narrow angle of view of the lens, a single frame does not provide the synoptic view of the landscape otherwise recorded with conventional aerial camera systems. Consequently, sampling techniques need to be developed whereby 70-mm photography is used to sample strips of the landscape photographed simultaneously on film of conventional format.

The use of color aerial photography, especially large scale, for rangeland vegetation inventory and surveillance is new. Many problems are yet to be solved. It is not expected that all plant species would be identifiable or even detectable in the photographs because of small plant size and resolution of the photographic system. The resolution threshold for individual plants or plant groupings, and when during the growing season specific plants can be consistently identified with an acceptable degree of accuracy, need to be determined. We also need to determine whether the photographic image of a species differs among locations where it grows.

More latitude may be tolerated in seasonal procurement of photographs to identify plant communities or sites, since images of the total community system rather than individual species are of interest. Additional work is needed to determine when during the year community systems might best be differentiated.

Perhaps the most fundamental problem in use of color aerial photography at any scale for rangeland vegetation inventory and measurement is replication. To be completely useful, such photography should monitor changes in vegetation over time from place to place. However, quality control is not yet adequate in the manufacture, exposing, processing, or reproduction of the aerial photograph to assure consistent duplication of image color. In all cases, ground sampling is essential in conjunction with photointerpretation.

It is conceivable that the use of color aerial photography to provide rangeland resource information is a new area of research, in which new concepts must be developed and tested. It is conceivable that rapidly acquired color aerial photographs could be coupled with automated interpretation and quantification systems controlled by ground sampling to provide better information at less cost than ground sampling alone.

Driscoll, Richard S.
1971. Color aerial photography--a new view for range management. USDA Forest Serv. Res. Pap. RM-67, 11 p., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

Shrubs such as antelope bitterbrush, big sagebrush, snowberry, and true mountainmahogany can be identified more consistently on large-scale (1:600-1:1,200) color infrared aerial photographs than on the same scale color aerial photographs. Identification of relatively large forbs, including Fremont geranium and orange sneezeweed, is also easier on large scale color infrared. Neither film type appeared to give improved information regarding site delineation on smaller scale photographs. Other features of the range environment, including rodent disturbances, can best be identified on color infrared at photo scales up to 1:2,400. All of this depends on obtaining photographs at the right time of year in respect to phenology of the vegetation.

KEY WORDS: Aerial photography, infrared color photography, color photography, indicator plants, forest surveys, range surveys, land classification, forage plants, phenology.

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Common and Botanical Names of Plants Mentioned

LACK MESA:

Fescue, Idaho	*Festuca idahoensis* Elmer
Fescue, Thurber	*Festuca thurberi* Vasey
Fleabane, aspen	*Erigeron macranthus* Nutt.
Geranium, Fremont	*Geranium fremontii* Torr.

NITOU:

Fescue, Arizona	*Festuca arizonica* Vasey
Grama, blue	*Bouteloua gracilis* (H.B.K.) Lag.
Pussytoes	*Antennaria* sp.
Sagebrush, fringed	*Artemisia frigida* Willd.

EMMLING:

Bitterbrush, antelope	*Purshia tridentata* (Pursh) DC.
Rabbitbrush	*Chrysothamnus* sp.
Sagebrush, alkali	*Artemisia longiloba* (Osterhout) E
Sagebrush, big	*Artemisia tridentata* Nutt.
Snakeweed, broom	*Gutierrezia sarothrae* (Pursh) Br Rusby
Snowberry	*Symphoricarpos* sp.

McCOY:

Juniper, Rocky Mountain	*Juniperus scopulorum* Sarg.
Mountainmahogany, true	*Cercocarpus montanus* Raf.
Pine, pinyon	*Pinus edulis* Engelm.
Sagebrush, big	*Artemisia tridentata* Nutt.

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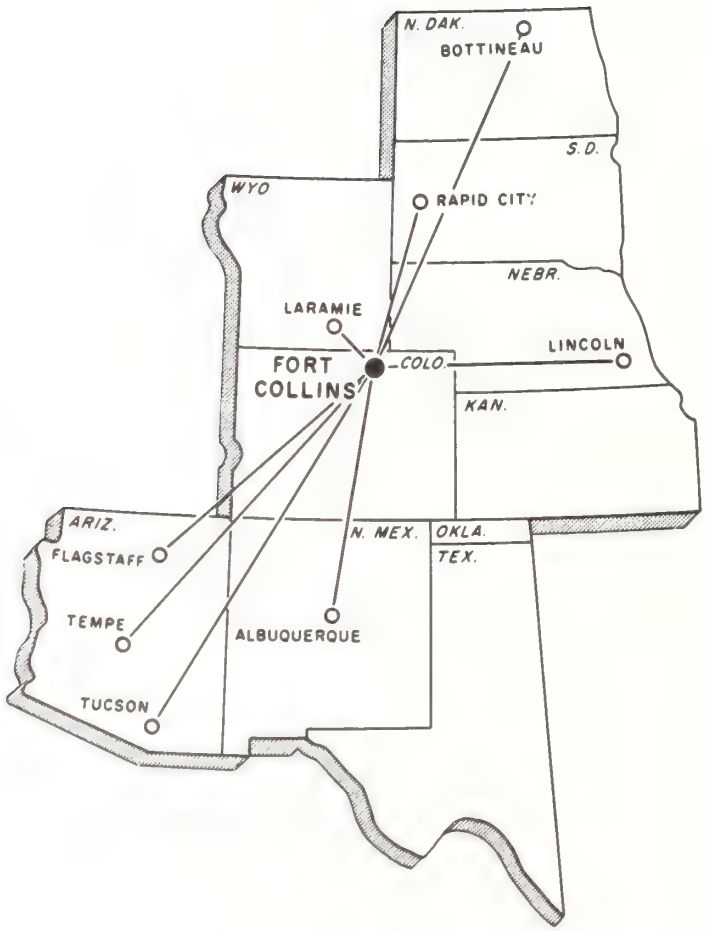
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characteristic and processes of soil piping in gullies

By Burchard H. Heede

ky Mountain Forest & Range Experiment Station — Forest Service — U.S. Department of Agricultu

Abstract

Soil piping processes and soil development were studied as a result of combined pipe and gully actions. Soils from gully side slopes with and without pipes showed a highly significant difference in exchangeable sodium percentage (ESP). Piping soils had a layer permeability 2 to 12 percent of that of soils without pipes. Both soils were fine textured. The interior of one soil pipe was thoroughly inspected, surveyed, and photographed from inlet to outlet. Based on the survey, and chemical and mechanical analyses, it is proposed that soil pipes on the Alkali Creek watershed developed mainly from soil cracks. Other causes such as rodent holes or dead root canals are presumed possible, but were not verified. Gullies, high exchangeable sodium percentage, low gypsum content, and fine-textured soils with montmorillonite clay appear to be prerequisites to the formation of soil pipes on the study area.

ESP was significantly higher in piping soils in place than in those fallen from the gully side slopes. ESP decreased also with increasing time since fall. Natural reclamation of the fallen soils led to processes initiating gully stabilization.

KEY WORDS: Gullies, soil erosion, soil permeability, soil stabilization.

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March 1971

Characteristics and Processes of Soil Piping in Gullies[1]

by

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Rocky Mountain Forest and Range Experiment Station[2]

[1]Part of this study was included in a dissertation submitted in partial fulfillment of the requirements for the degree of Ph.D. to Colorado State University, June 1967.

This study was made in cooperation with the Rifle Ranger District of the White River National Forest, Glenwood Springs, and Region 2 Office of the U. S. Forest Service, Denver, Colorado.

Helpful suggestions on chemical analyses were given by Drs. Donal D. Johnson and Willard R. Schmehl, Professors of Soils, Colorado State University.

[2]With central headquarters located at Fort Collins, in cooperation with Colorado State University.

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Characteristics and Processes of Soil Piping in Gullies

Burchard H. Heede

Present Knowledge

The piping of soils has been recognized on different continents for several decades. This type of erosion, in which the soil is carried away by water running through holes in the ground, has also been called pseudokarst, tunneling erosion, and pothole erosion.

A thorough knowledge of the processes involved in soil piping is necessary for successful and economical control projects, especially in the Southwest where soil pipes occur frequently. This paper presents a comparison of soils from sites with and without pipes. On the basis of chemical and mechanical analyses, permeability tests, topographic surveys, and thorough visual inspections, some of the older hypotheses on soil piping are verified, others rejected. Soil piping was observed on the study area for more than 4 consecutive years. During this time a complete topographic survey of a soil pipe, pictures of its interior, and analyses of soil and sediment samples from the interior and from flows through the pipe were made. These observations indicated that piping may not only lead to a karstlike topography along gullies, but may indeed help induce reclamation of the soils. Based on this hypothesis, a second study was initiated to show the influence of piping on soil reclamation in gullies.

Literature

The literature on soil piping and hypotheses on the piping processes were thoroughly reviewed by Brown (1961) and therefore, need not be repeated here. Where pertinent, older investigations will be referred to in the text. Reviewed here will be only that literature which relates soil characteristics to soil piping.

The role of sodium in the processes of dispersion and flocculation of soils was studied some 40 years ago on the high plateau of Colorado, Utah, and Wyoming, and in the sediment load of Colorado River water (Breazeale 1926). This study demonstrated that erosion hazards may be drastically increased by the presence of sodium, which increases the dispersibility of soils. In recent field experiments on the erodibility of some South African soils, Hiemstra (1965) could distinguish between relatively stable (less erodible) and unstable soils by their sodium content. While stable soils contained extractable sodium cations of 0.1 meq./100g., unstable soils had between 0.2 and 1.2 meq./100g.

The influence of sodium on the dispersion and permeability of soils has been studied by several researchers. They demonstrated that the type of sodium compound as well as the level of saturation of the soil influence soil permeability. Thus, Ramdas and Mallik (1947) found in India that a 5 percent solution of sodium chloride and a 1 percent solution of sodium carbonate each increased permeability four times. In England, Quirk and Schofield (1955) saturated soils with sodium ions by passing molar sodium chloride solution through them for 12 hours. When this solution was replaced by more dilute solutions of sodium chloride, in each case permeability decreased with time throughout the observation period of 5 hours. This decrease was thought to result from swelling, and then deflocculation.

In canal sealing studies, clays with high sodium content were found to produce a desirable high degree of dispersion of the channel soils (Dirmeyer and Skinner 1964). Swelling and dispersion, along with other processes, are associated with the structural breakdown of soils. Their combined effects can be expressed in an air-water permeability ratio.

This ratio was introduced by Reeve (1953) as an expression of the stability of soil structure, who found that the permeability ratio increased exponentially with increasing exchangeable sodium (Reeve et al. 1954). When the ratio was tested later on seven different soils, it was shown again that exchangeable sodium has a marked effect on the stability of soil structure (Brooks and Reeve 1959).

The importance of sodium in soil piping processes has been considered by only a few investigators (Brown 1961, Fletcher et al. 1954). These authors advanced the hypothesis that sodium is a contributing factor to the severity of piping, but not a necessary constituent for the occurrence of pipes. They were led to the second thought by the range in values of sodium at locations where piping is prevalent. Parker and Jenne (1967), without presenting data, state that high percentages of exchangeable sodium can be responsible for the occurrence of pipes, but that large amounts are not prerequisite in all cases, and conclude that such cases of piping may occur "due to subsidence, loess, and possibly other low-density previously unsettled earth materials." Nearly all investigators stated that the processes of soil piping lead to a widening of gullies. Leopold et al. (1964) reported soil pipes to be an important element in the headward extension of discontinuous gullies. Where pipes were located up-valley from the head cut, the up-valley progression of the head cut was accelerated by the piping processes. Since, as these authors observed in New Mexico, the pipes often extend into the ungullied alluvium for distances of several hundred feet, tributary gullies will form by the collapse of tunnels extending from the gully side walls.

Natural reclamation of soils was first reported from the Solonetz regions of southern Russia (Vilenskii 1957) where, due to increases in steppe or meadow vegetation, the soils were enriched in organic matter and calcium. This enrichment, in turn, led to a gradual transformation toward chernozemic and chestnut soils.

Apparently absent from the literature on piping are references to (a) surveys of soil pipe geometry, both external and internal, (b) analyses of soils from pipe walls, (c) local variations in soil characteristics as related to presence or absence of pipes, (d) frequency and magnitude of pipe flows, (e) character of sediment yielded from pipes, (f) chronology of pipes, and (g) influence of pipes on soil development.

The Study

Study Area

The study area is located on the upper Alkali Creek watershed of the Rifle Ranger District, White River National Forest, 20 miles south of the town of Silt, Colorado. The area is part of the Uinta Basin of the Colorado Plateau Province, and represents a dissected plateau with strong relief. Gullies carry water only during spring snowmelt and intense summer storms. Rocks of the watershed are tertiary sandstones and shales of the Wasatch formation, which consists chiefly of variegated clay shale and irregular, crudely bedded sandstone (Fox and Nishimura 1957). In general, the soils are predominantly formed from fine-textured, loose, unconsolidated shales with an admixture of sand from beds of sandstone. Although the regolith is generally rather thin, alluvial deposits in excess of 6-foot depth are found on the main valley bottom. Soil piping is most extensive here. The area is representative of the oakbrush-sagebrush grasslands of the Western Slope of the Rocky Mountains in Colorado. Precipitation, the only climatic factor measured on the study area, averaged 18.5 inches in 1962 and 1963.

Study Method

The study consisted of two parts. The first, an investigation of soil piping processes themselves, lasted from 1962 to 1967. The second part, concerned with soil development as a result of combined piping and gully processes, was terminated in 1968.

Processes

For the study of piping processes, three soil pipes were selected whose inlets and outlets could be clearly identified. For two of the pipes, catchment devices were designed to collect the water and sediment leaving the pipes (fig. 1). These devices consisted of a large, flat funnel connected to two 55-gallon drums. The upper side of the funnel which could be removed for cleaning, prevented rain or snow from entering the system. The lower edge of the funnel was placed flush with the bottom of the soil pipe without changing the general charac-

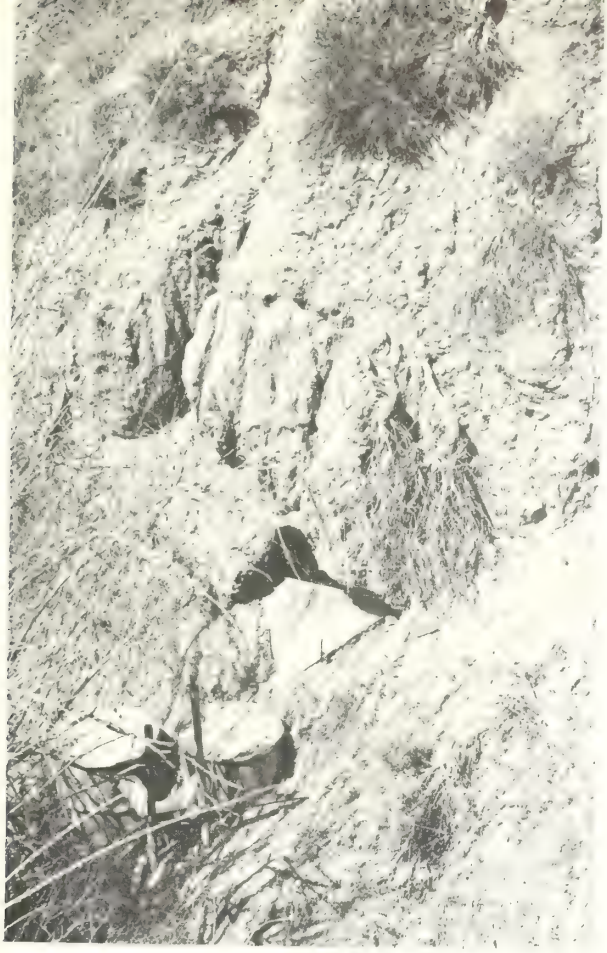
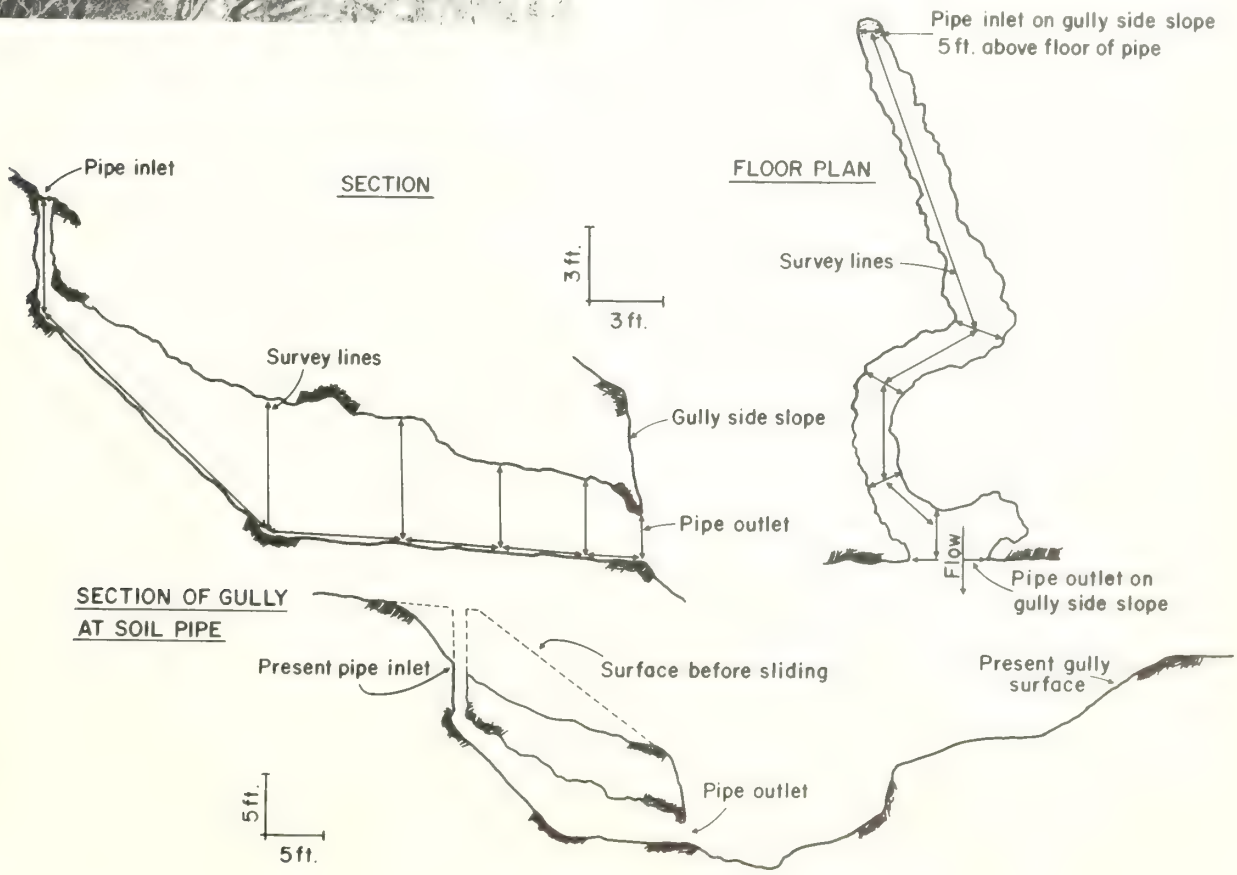


Figure 1.--Collector funnel with catchment barrels installed at outlet of soil pipe 1, which is 3 feet above gully bottom.

teristics of the outlet. When an observer was present, flow was collected with an ordinary milk bottle. Soil samples were collected from gully side slopes with and without soil pipes. The side slopes were sampled at different elevations to demonstrate development of soil characteristics with depth.

The full interior length of a pipe was surveyed and photographed, and soil samples were taken from interior walls. To minimize danger, it was surveyed in autumn when the soils were dry. The narrowness of pipes on Alkali Creek made the survey a difficult one-man task (fig. 2). Thirteen samples

Figure 2.--Floor plan and section of soil pipe 1. The cross section of the gully shows the layout of the pipe relative to the channel. Note that the height of the pipe is much larger than its width, and that the pipe outlet is above the gully bottom.



were removed from the interior of the pipe. All soil and sediment samples were subjected to chemical and mechanical analyses, and permeability tests. For the latter, fragmented samples were used (Dirmeyer and Skinner 1964). The Soils Testing Laboratory at Colorado State University chemically and mechanically analyzed the soils according to the procedures outlined in USDA Agriculture Handbook 60 (U. S. Salinity Laboratory Staff 1954). Sediment concentrations were calculated for the pipeflow samples.

Soil Development

For the investigation on reclamation of soils, samples were collected from each of four locations with a piping side slope and soils fallen from these slopes. The fallen material was categorized into soil blocks, small colluvial cones, and soils fallen on the side slope opposite from the piping bank.

Soil blocks were formerly parts of Solonetz columns that had broken from the piping slopes. These blocks (each 1 cubic foot or more in volume) were almost intact, although they showed small seams and cracks caused by the impact of the drop. The time since fall was known to have been not much greater than 3 years.

The small colluvial cones consisted of soil particles ranging in diameter from sand to about 1 inch. The cones were formed below small chutes on the piping slopes by deposition of soil particles that had been moved by gravity, frost action, animals, and other forces.

Soils fallen on opposite side slopes contributed the largest volumes—as much as 15 cubic yards.

The original soil columns of the alluvial soils were completely shattered when dropped or, in one case, destroyed by erosion a few years later. Normally, vegetation grew on these dumps. To some extent, the loose material below and opposite

Figure 3.--Inlet of soil pipe 1 on sliding surface of gully side slope (see fig. 2). Length of ruler is 5 inches. Note the crusting and sugaring of the clayey alkaline soil.

from the piping slopes represented different degrees of both destruction of the original soil structure and mixing of the piping soils. The material fallen from the wall opposite the piping slopes showed the strongest degree of aggregate destruction and mixing. The material from colluvial cones showed less change. Soil blocks were little changed. For the purpose of this study, piping side slopes were classed as intact.

Results

Layout of a Representative Soil Pipe

Soil pipe No. 1 was selected for detailed surveys because its size allowed physical inspection of the pipe interior, and additional data on soils, sediment, and flows were available. The pipe was also regarded as representative of many others on the area. The pipe did not follow a straight line from the pipe inlet to the gully (fig. 2). Height within the pipe was two to six times greater than width. This ratio is typical for pipes investigated in the study area. Also typical is the pipe gradient from inlet to outlet. The pipe begins with a nearly vertical segment, then enters into a 45-degree reach, and ends with a gentle gradient of a few degrees. The inlet of the pipe was located outside the gully until the side slope slid into the gully, about 3 years before the survey. The cause of the slide is unknown. The inlet is now on the gully side slope (fig. 3) 3 feet above gully bottom. Not one pipe was found on the area with its outlet close to channel floor elevation. This pipe is located entirely in alluvial soil with very pronounced strata (fig. 4).

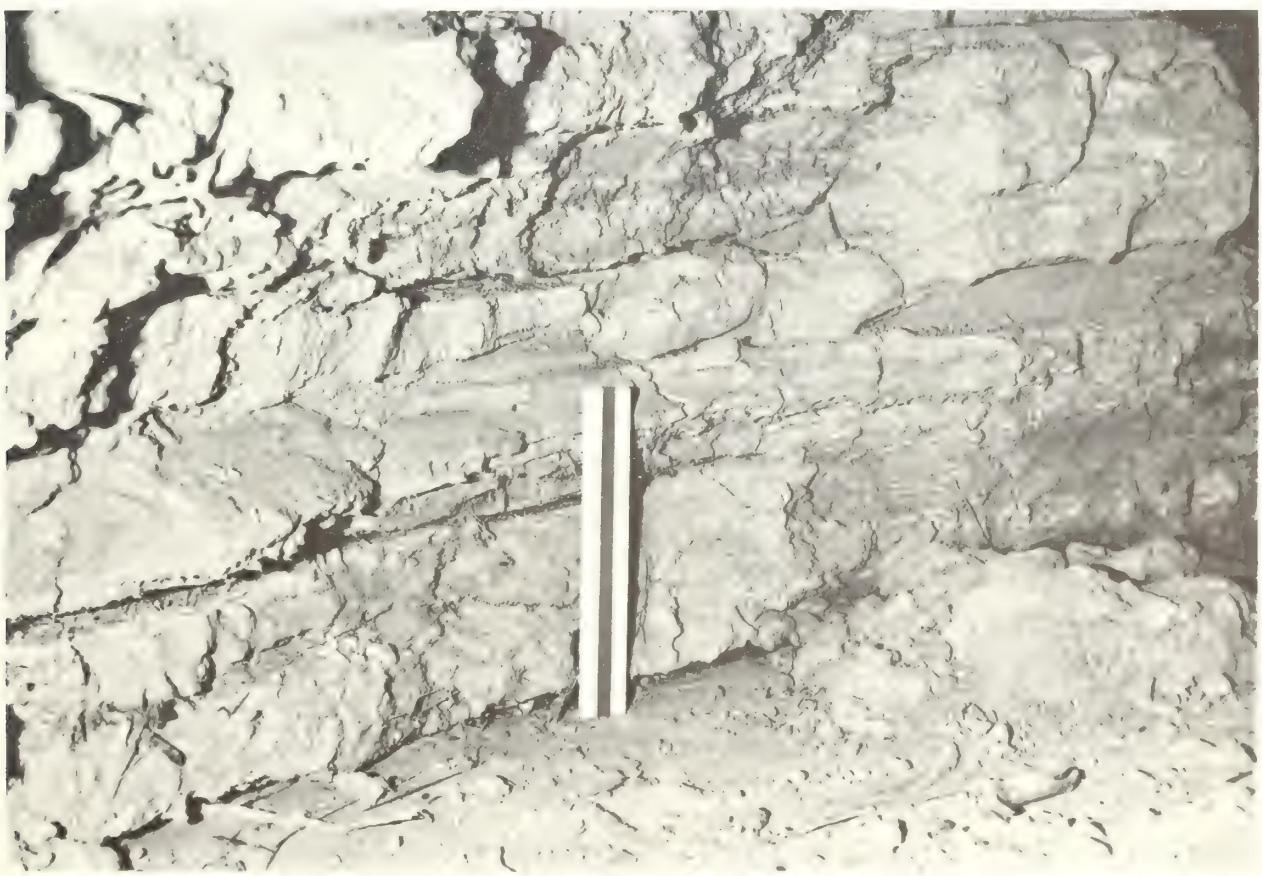


Figure 4.--Interior of soil pipe 1, 12.5 feet from the pipe outlet. Pronounced strata of the alluvial soils are typical for this pipe. The 2-inch iron pipe is on the floor of the pipe. Roots in the lower layers are from sagebrush growing on the gully side slope.

Characteristics of Piping and Nonpiping Soils

Piping soils had a significantly higher exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) than nonpiping soils (table 1). ESP is the degree of saturation of the soil exchange complex with sodium, and may be calculated by the formula:

$$ESP = \frac{\text{Exchangeable sodium (meq./100 g. soil)}}{\text{Cation exchange capacity (meq./100 g. soil)}} \times 100$$

SAR is calculated from:

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{++} + Mg^{++})/2}}$$

where the ionic concentrations of the saturation extract are expressed in terms of milliequivalents per liter. While all exchangeable sodium percentages for nonpiping gully side slopes were less than 1.0, those for the piping slopes were greater than 1.0 and averaged 12.0. Susceptible soils also differed from nonpiping soils in pH and gypsum content. Because the higher pH of piping soils is due to their higher ESP's, pH must be regarded as a dependent variable. The highly significant difference in gypsum appears not to be meaningful because the amount of gypsum is too low to exert a tangible flocculating influence on the predominantly sodium-influenced soil. Larger segments of the gullies were sampled intensively for gypsum, but no greater concentrations were found. Calcium carbonate was present, but under the prevailing conditions was probably not effective because of its small amounts and low solubility.

Piping soils had a statistically greater conductivity than stable soils, but the conductivity, a measure of soluble salt in the soil, was not high enough in the majority of these soils for them to be considered saline. With the exception of one sample, analyses of the cations present in the saturation extract of the piping soils showed a great excess of soluble sodium over calcium and magnesium. Sodium ion concentration averaged 12.2 milliequivalents (meq.) per liter (standard error of the mean 2.6) while mean calcium plus magnesium ion concentration was 1.4 meq./l. (standard error 0.2) for 12 samples. Potassium ions were not found in significant amounts.

With such high soluble sodium levels relative to those of calcium and magnesium, the piping soils contained sufficient sodium to insure dispersion when water moved through them. In contrast, the stable soils did not contain enough sodium for dispersion

Table 1.--Comparison of soils with and without pipes

Soils	Exchangeable sodium percentage	Sodium adsorption ratio	pH (1:5)	Gypsum	Conductivity at 25° C.	Moisture at saturation	Sand	Silt	Clay	Textural class	Number of samples
				meq./100 g.	mmhos/cm.	- - - Percent - - -					
Without pipes (Stable)											
Average	<1.0	0.4	7.6	0.7	0.5	45.1	25.4	26.8	47.8	Clay	19
Standard error of the mean	--	.07	.14	.06	.05	1.35	2.53	1.33	2.13		
With pipes (Unstable)											
Average[1]	12.0**	10.7**	8.9**	1.6**	1.7*	38.7	30.7	23.5	45.8	Clay	13
Standard error of the mean	2.27	2.0	.17	.19	.37	3.16	4.05	2.39	2.87		

[1]Statistically significant differences between soils with and without pipes: **highly significant; *significant.
[2]For ease of statistical calculations, a mean of 1.0 instead of <1.0 and a standard error of 0.0 were used.

and swelling to take place. Since both piping and nonpiping soils were clay, there was no significant difference in the mechanical analyses. Soil moisture at saturation is dependent on the amount of clay in these soils, and therefore was also not significantly different.

Nonpiping side slopes had a more gentle gradient and were well covered by vegetation. In contrast, piping gully side slopes were steep, unstable, had a "sugary" soil surface, and usually had no or sometimes very sparse vegetation.

To trace the origin of the sodium in the soils, samples from shale of the Wasatch formation, underlying the alluvial soils, were analyzed. Values for ESP and SAR were high in all samples (table 2) and indicate that the shale delivered most of the sodium to the soils. Gypsum content was low, as in the alluvial soils. The shale had high pH values due to the influence of the sodium.

Soil samples from four different levels were collected and analyzed to test whether chemical characteristics and/or particle size distribution of the soils with pipes differed with depth (table 2). With the exception of the sample from 1-foot depth at pipe 1, all values for ESP were greater than 1.0. All pipes showed some continuous decrease of sodium with depth after the maximum value was obtained about half-way between brink of bank and gully bottom. Yet, none of the lower levels had values close to those of stable gully side slopes, and there was no tendency for greater soil dispersion adjacent to or beneath the pipe outlets. Gypsum content was very low in all samples. Variations in the mechanical composition of the soils by depth were small. Soils from the inlet and outlet of pipe 1 showed close agreement between ESP, gypsum content, and texture, and the values did not deviate significantly from those of the depth samples. Samples from the interior of pipe 1 at a location about 10 feet below the ground surface and 12.5 feet inside the gully side slope, as measured from the pipe outlet, were also high in exchangeable sodium and low in gypsum (table 2).

It is noteworthy that cloudburst storms did not produce pipe flows. The pipes supported flows only during spring snowmelt. Two samples from these flows carried large sediment loads with much greater concentrations of sodium (140 p.p.m.) than calcium (10 p.p.m.) or magnesium (18 p.p.m.). Since the loads were derived from soils of the piping slopes, the sediment deposits in the catchments below pipes had ESP values greater than 1.0, high pH, weak conductivity, and low gypsum content (table 2). The deposits were relatively high in silt content due to the ease of removal by flows of small magnitudes.

Table 2.--Supplementary soil analyses, with mean and standard error (S.E.)

Source of soil	Exchangeable sodium percentage		Sodium adsorption ratio		Conductivity at 25°C.		Gypsum		pH		Number of samples
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	
					mmhos/cm.		meq./100g.				
Shale parent material	17.9	1.5	15.7	1.5	0.8	0.1	0.9	0.49	9.7	0.09	4
Gully side slopes:											
Brink	11.2	9.5	11.2	9.3	1.1	.8	.1	.04	--	--	6
Midway	26.7	1.9	25.6	2.4	1.7	.3	.2	.06	--	--	6
Pipe outlet	16.0	3.4	14.2	3.3	.8	.2	.1	.03	--	--	6
Bottom	11.4	3.8	10.0	3.2	.5	.2	.1	.03	--	--	6
Alluvial layers inside pipe	10.1	1.2	8.7	1.0	2.6	.5	.2	.03	9.5	0.03	13
Pipe inlet	13.1	2.8	11.1	2.5	1.9	.6	1.8	1.0	8.6	.4	2
Pipe outlet	14.8	7.5	13.3	7.0	2.2	.8	1.4	.2	8.9	.2	2
Sediment from pipe flow	7.2	1.6	6.2	1.3	--	--	--	--	8.6	.0	2
Deposited below pipes[1]	10.3	.4	8.7	.4	.9	.07	.1	.01	9.4	.04	10

" -- " indicates not applicable.
[1]From snowmelt flow during springs of 1964 and 1965 from soil pipe 1.

Characteristics of Piping Soils in Place and Fallen

If ESP is expressed as a function of soil disturbance (fig. 5), the decrease from undisturbed soils (piping slopes) to the most disturbed soils (falls on slopes opposite from piping banks) is statistically significant. According to conventional practice (U. S. Salinity Laboratory Staff 1954), the determination of Solonetz soils is based on ESP and conductivity. It was therefore not surprising to find that occurrence of Solonetz was greatest in the least disturbed soils.

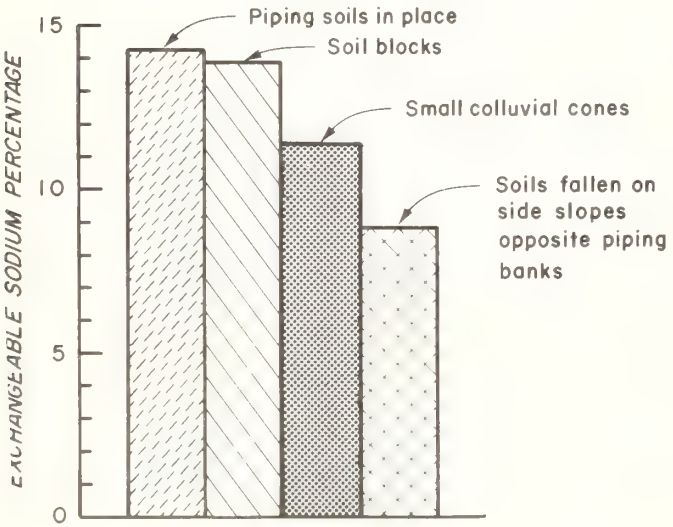


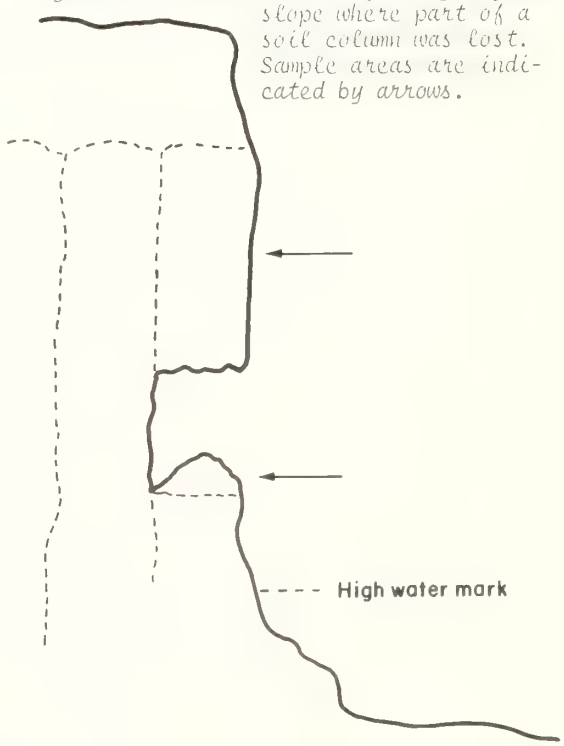
Figure 5.- Exchangeable sodium percentage as a function of in place and fallen piping soils.

To demonstrate the development of ESP values between soils related to each other beyond doubt, two sites were selected for sampling where part of Solonetz soil columns had broken out naturally from the gully side slopes about 1 year before sampling. In each case, an opening about 9 inches high had formed in the column (fig. 6). On the bottom of the opening, loose material from the column above accumulated in small piles. The piles were above the high-water marks of the gully flows during the previous 2 years. ESP of the columns above the openings and the soil in the piles were as follows:

Soil columns	Soil piles
17.4	13.9
16.5	16.0

In each case, values for ESP decreased with disturbance. This finding corresponds with results obtained from a recent study on deep plowing of Solonetz soils in Canada (Bowser and Cairns 1967). Deep plowing, representing physical destruction of the original soil structure, led to an increased exchangeable-calcium to exchangeable-sodium ratio.

Figure 6.--Cross section of the gully side slope where part of a soil column was lost. Sample areas are indicated by arrows.



For one location, time scales for occurrences of soil falls were established and ESP and conductivity of the saturation extract expressed as a function of age (fig. 7). In view of the relatively short periods involved (up to about 3 years), the decreases with time are substantial—almost 50 percent. Such a decrease in conductivity reflects a decrease of the salt complex in the soils. The rapid decrease of the salts must be explained primarily by leaching. The time intervals of figure 7 should be regarded as approximations to the nearest year.

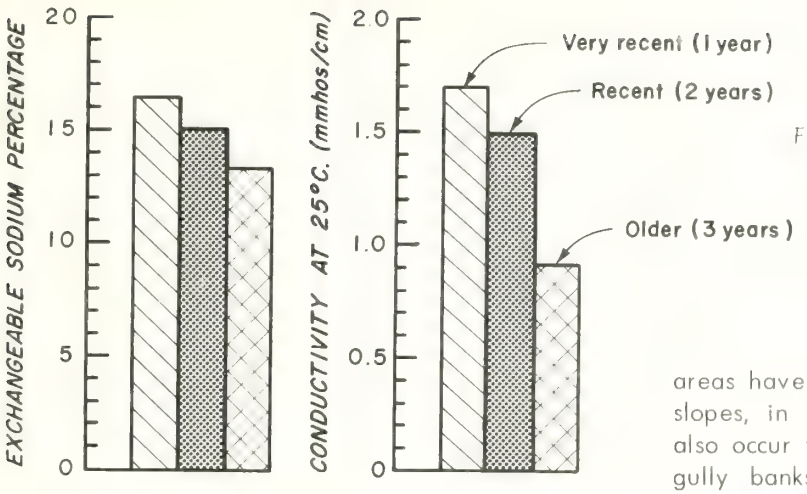


Figure 7.--Conductivity and exchangeable sodium percentage related to age of soil fill.

Discussion

Soil Piping Processes

Of the many hypotheses advanced on the causes and development of pipes, rodent burrows (Carroll 1949), canals formed by dead roots (Carroll 1949), land denudation by overgrazing (Downes 1946, Fletcher and Carroll 1948, Kingsbury 1952) and soil cracks (Downes 1946, Brown 1962), were most frequently mentioned. There is little doubt that rodent holes, root canals, and deep soil cracks may lead to the formation of pipes on Alkali Creek watershed if a sufficient hydraulic gradient for runoff is provided by a lower base level such as represented by gullies. But based on the following reasoning, it is suggested that on the Alkali Creek watershed a dispersing agent such as sodium must be present in the soils as a prerequisite.

Older studies on the area have shown that the clay has montmorillonite structure (Brown 1961). This type of clay is characterized by a strong rate of swelling and shrinking, and soils containing this clay mineral tend to develop cracks. Since the clay content is high in all soils of Alkali Creek watershed, soil cracks were not confined to areas with sparse or no vegetation, but were also found in areas with dense vegetation cover. These latter areas have nonpiping, relatively stable gully side slopes, in spite of the fact that deep soil cracks also occur there. Pipes do develop, however, on gully banks and side slopes where the ESP is greater than 1.0, although the exact breaking point at which pipes may develop cannot be given. All pipes detected on the watershed were located close to the gullies. No pipe inlets were found at a distance greater than 25 feet from the present edge of the gully.

The shape and alinement of soil pipe 1 (fig. 2), typical of pipes in the area, indicated that the pipe followed a former soil crack. The pipe was narrow (fig. 8) and, if viewed from within, showed

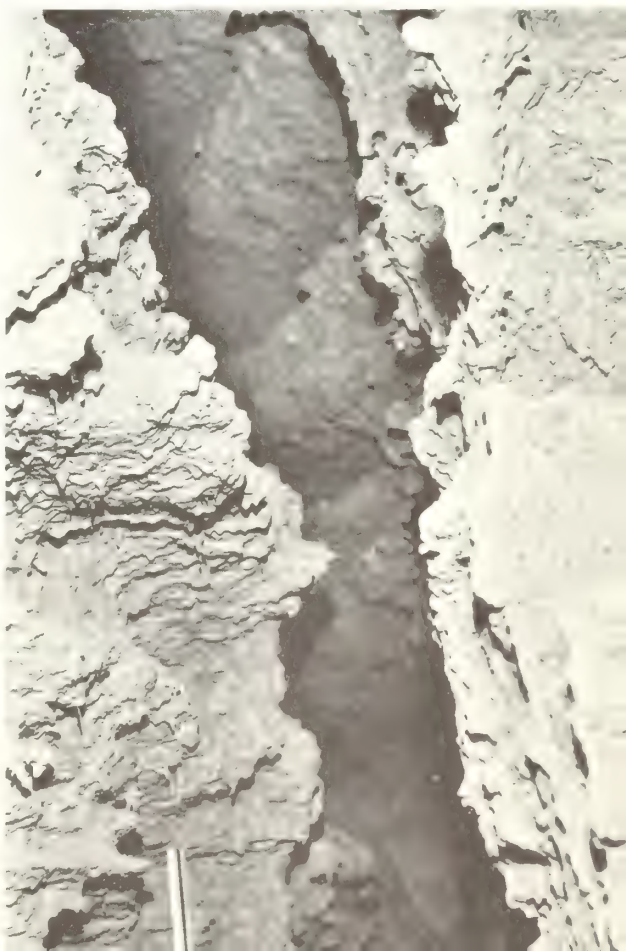


Figure 8.--Upstream view inside soil pipe 1 at a location 18 feet from gully side slope. The ruler is 6 inches long. Note the narrowness of pipe relative to its height, which indicates former cleavage line in the clayey alluvial soils. The pipe continues with a sharp bend to the left.

the seam of a continuous crack on its ceiling, which appeared to be the remnant of the original line of cleavage. Since the soils of gully side slopes and banks dry out much faster than those of undissected areas away from gullies, cracks will start at the gullies. Later runoff follows these cracks down to the channel. Where sodium content reaches a certain level, the clayey-silty soils are easily dispersed and carried into the gully. This process leads to a widening of the crack at its bottom where the water runs. Once the hole is sufficiently wide, the crack above the widening closes due to gravitational action and a so-called soil pipe has been formed. The capability of the soils for arching is illustrated by a natural soil bridge (fig. 9). In contrast, where a dispersing agent is not available, erosion in the cracks is so slow that the cracks will close again during swelling of the soils.

Wetting of the soils may be as important as dispersion for the piping processes. Laboratory experiments demonstrated that the layer permeability of soils with ESP values greater than 1.0 ranged between 1.6 percent and 11.8 percent of that of soils with ESP less than 1.0 (fig. 10). This means that wetting and, with this, swelling of the sodium soils is much slower than of nonsodium soils, and suggests that cracks in the sodium soils remain open much longer. Also, more water is available for flows through the cracks where the ESP is higher because of decreased infiltration and increased surface runoff. The increased flow will cause increased erosion in these cracks.

Figure 9.--Upstream view of a gully on Alkali Creek watershed. Length of rod placed under natural soil bridge is 5.5 feet. Unstable gully side slopes with soil piping typically alternate with stable slopes indicated by a vegetation cover in the right foreground and in the background of gully. Bridge appears to be remnant from an older soil pipe.

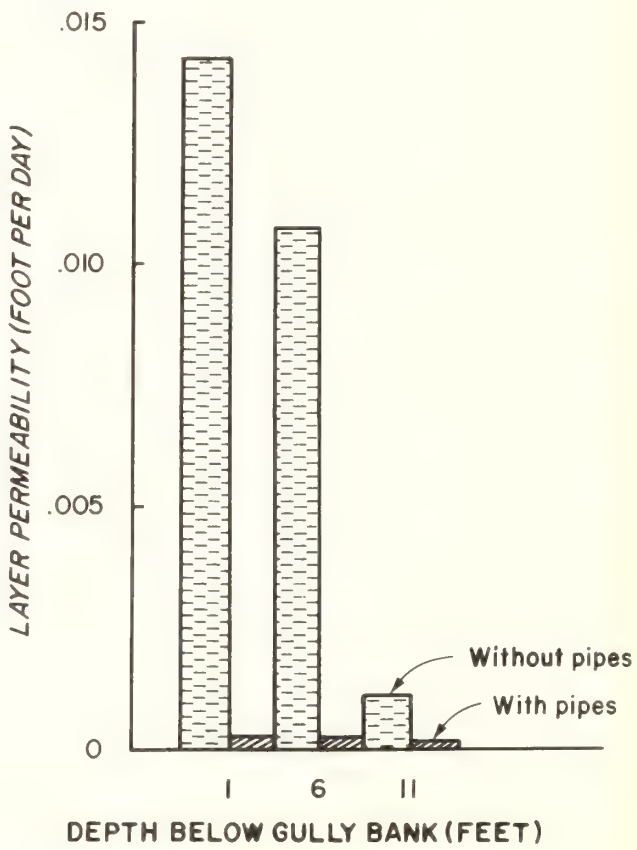


Figure 10.--Layer permeability of gully side slopes, with and without soil pipes by depth below bank of gully.

At first, the development of the pipe gradient from extremely steep to very gentle appeared puzzling. The question arose as to what caused the breaks in gradient, especially where the flow seemed to head deterministically toward the gully and did not continue its downward movement. Since the soils of the lower part of the gully side slopes remain moist for a much longer period of time and dry at a rate much slower than those of the upper part, soil cracks will start above the moist zone where drying is very rapid after the last runoff from spring snowmelt (fig. 11). Thus, it can be assumed that the original configuration of a soil crack provides the longitudinal profile characteristic for the pipe. Surface runoff, entering a crack, will be well loaded with sediment when it reaches the low part of the pipe. Due to the gentle gradient there, velocities of flow will decrease, and in turn, the load-carrying capacity of the water decreases. Thus, the rate of erosion on the bottom of the lower pipe is small and, in time, aggradation will occur instead of degradation. Strata of high dispersion in a soil profile may also act as impermeable layers and thus could be a cause for the changes in longitudinal gradients of pipes. The occurrence of an impermeable substratum was proposed by earlier research (Downes 1946). Yet our analysis showed that the exchangeable sodium percentage decreased at lower depths (table 2). Layer permeability values for samples from gully side slopes on piping soils did not decrease for depths greater than 1 foot below the soil surface (fig. 12).

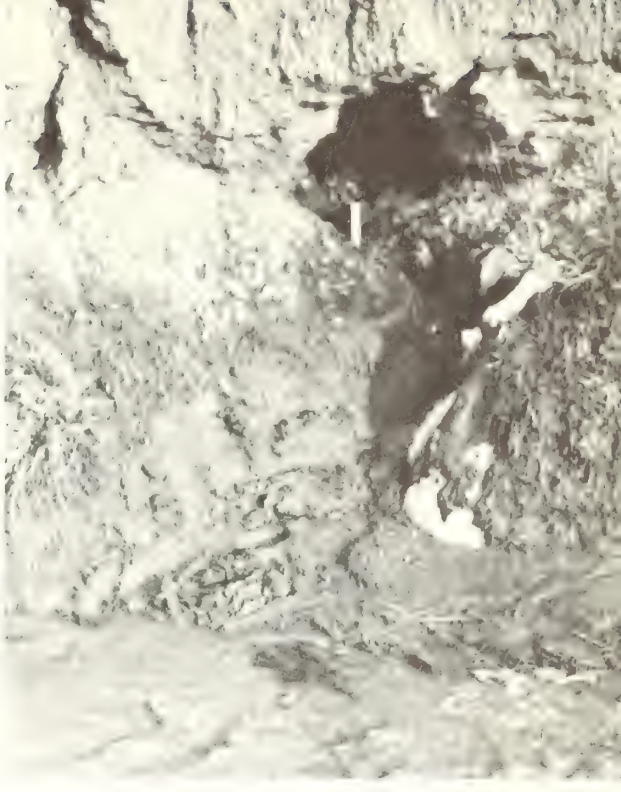


Figure 11.--The outlet of soil pipe 3, located about 4 feet above the gully bottom, during the spring snowmelt of 1963. Recent pipe flow, exhausted by lack of snow outside of the gully, caused the erosion on the gully side slope below the outlet. The increased slope gradient below the pipe outlet raised the load-carrying capacity of the pipe flows and thus made this erosion possible. Snows in the headwaters still feed the flow in the gully. Note the wetting of the gully side slope to the approximate elevation of the pipe outlet. Ruler is 4 inches long.

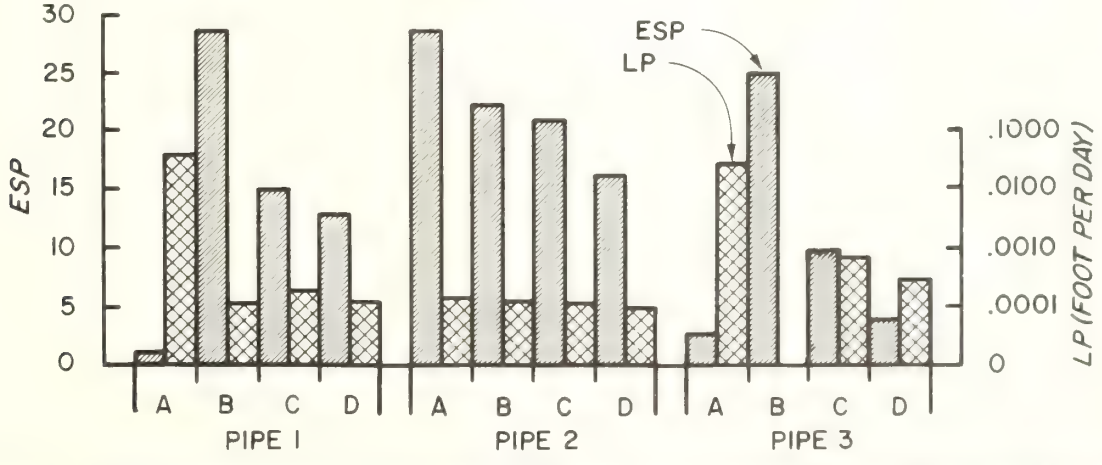


Figure 12.--Exchangeable sodium percentage (ESP) and layer permeability (LP) of piping soils, by depth, for three soil pipes.
A = 1 foot below ground surface
B = midway between ground surface and pipe outlet
C = bottom elevation of pipe outlet
D = 1 foot below bottom of pipe outlet

Natural Reclamation of the Piping Soils

While the analysis of the samples from stable gully side slopes showed that all samples were derived from normal soils, part of the samples from piping side slopes represented Solonetz, if conventional guidelines (U.S. Salinity Laboratory Staff 1954) were applied. These guidelines propose a division of soils into sodium and nonsodium at 15 percent exchangeable sodium. This practice has been questioned since experiments have shown that, as the exchangeable sodium increases, the permeability to solutions, considerably less concentrated than the threshold concentration, decreases continuously (Quirk and Schofield 1955). The threshold concentration, which has no absolute value, was defined as that concentration of salt that causes 10 to 15 percent decrease in soil permeability—the concentration where factors which can cause drastic reduction in permeability are becoming operative. Most of the piping soils of the study area can be classified as soils with a tendency toward the formation of Solonetz, if we accept Gedroits' concept on the causes for Solonetz formation. Gedroits stated that the direct cause for such development is the adsorption of sodium by the soils while displacing exchangeable calcium and magnesium. That such displacement has occurred or is taking place at present, appears to be indicated by the large sodium ion concentration relative to the concentration of calcium and magnesium ions. In contrast to Russian Solonetz, the soils of the study area exhibit no or very weak horizons. Thus, our soils are of a much younger age. The youthfulness is also illustrated by very pronounced alluvial strata (see fig. 4). Yet, as is the case with Russian columnar Solonetz, our soils are also divided into well-defined columns below the surface soil layer (fig. 13). After

Gedroits, K. K. Solenetz, their origin, properties and melioration. 1928. Cited by Vilenskii (1957).

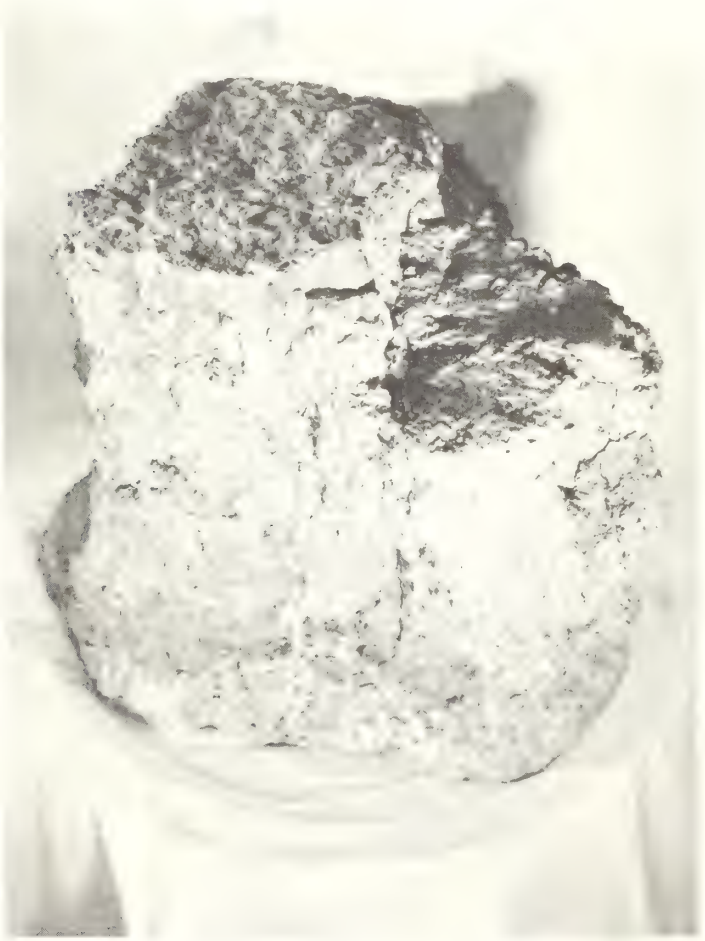


Figure 13.--This soil column was taken from a gully side slope with pipes. The section of the column constitutes a hexagon; its longest side measures 9 inches (there was some destruction during transport).

spring snowmelt, when the soils dry rapidly, the hitherto nonstructured soil mass is dissected into structured columns with polygonic cross sections. Most of the polygons have six sides; lengths of sides up to 8 inches were measured. Identical to the Russian Solonetz, the summits of the columns have lacquered surfaces, apparently from the drying of colloidal solutions on them.

Piping gully side slopes of the Alkali Creek watershed shear off repeatedly during rains and periods of heavy snowmelt, leaving nearly vertical cliffs. The soil masses are deposited on the opposite side slope, and force future gully flows against the piping bank (fig. 14). This leads to undercutting of the piping side slope, and results in more bank cleavage. With time, the thalweg migrates away from the deposition side slopes, and it appears that these slopes become stable. Growth of vegetation on the deposition slopes is favored by increased soil moisture. More water will infiltrate into the slopes due to the gentler slope gradient formed by the deposits. The soluble salts, a large proportion of which are sodium, may also be leached more easily from the soils after their mechanical disturbance. As sodium is leached from the soil, the pH will decrease and calcium will be more soluble and available for plant growth. The greater calcium influence will also stimulate flocculation and will speed the leaching process. While the leaching of sodium undoubtedly benefits the establishment of vegetation because the osmotic pressure in the soils decreases with decreasing salt concentration, calcium made available by the plants, in turn, will speed the leaching processes. Thus, gully side slope stabilization may progress rapidly, once plants become established.

Figure 14.--Piping gully side slopes break off in vertical cleavage lines. The soil masses are dumped on the opposite side slope. These slopes of deposition are invaded by vegetation, while the gully flows are forced toward the piping slopes. The length of the rod is 5.5 feet.

Field observations indicate that gullies with piping side slopes move laterally into the piping bank, and that lateral gully movement continues as long as piping banks are available. Since most of the material from the piping slopes falls on the opposite side slope of the gully, stabilization will occur there. Inspections showed that stable slopes are found on all aspects, and no aspect was favored. Typically for the study area, the gully side slopes opposite from pipes 1, 2, and 3 were classified as stable, with very little surface soil movement. It must be assumed that the soils with relatively high ESP values exist as lenses, a depositional form typical of alluvium. Once a gully has moved laterally through such a lens, the former piping bank may become stabilized, if deep cutting of the gully or other hydraulic adjustments such as meandering are not at work. The final stage of this development may resemble that of old age of a karst topography on a somewhat smaller scale. Our investigations did not permit the delineation of such areas on Alkali Creek watershed, although general observations indicated that they may exist. The study did show, however, that in each case, gully side slopes covered by fallen piping soils were in the process of stabilization.

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Exchangeable sodium percentage showed a highly significant difference between soils with and without pipes. Layer permeability of piping soils was only 2 to 12 percent of that of soils without pipes. The interior of one soil pipe was thoroughly inspected, surveyed, and photographed. Soil pipes on the Alkali Creek watershed probably developed mainly from soil cracks. Gullies, high exchangeable sodium percentage, low gypsum content, and fine-textured soils with montmorillonite clay appeared to be prerequisite to the formation of pipes. Soil piping appears to lead to natural reclamation of the soils, which in turn introduces stabilization processes of gully side slopes

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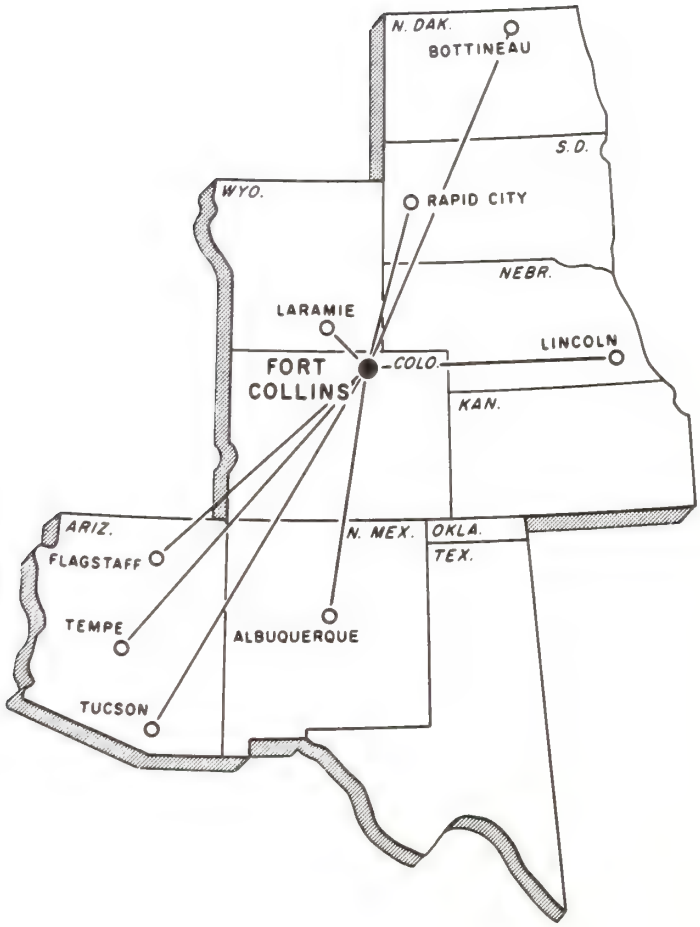
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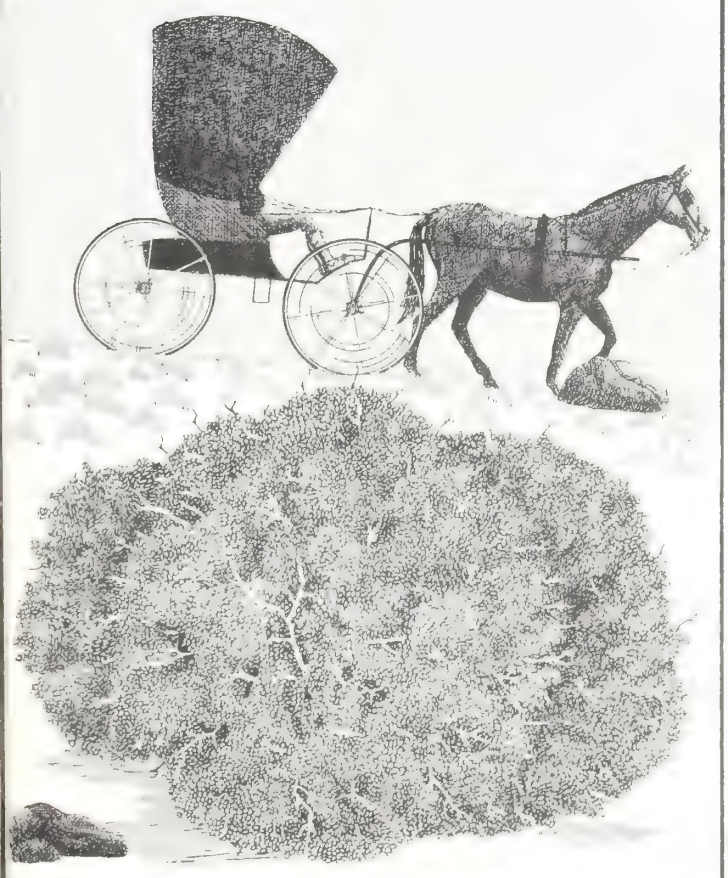

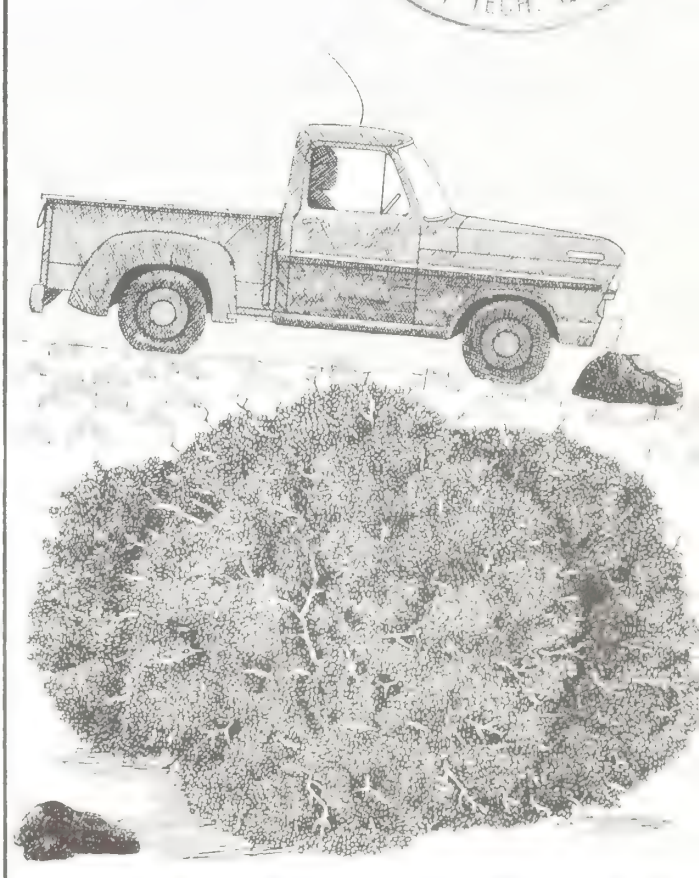

Rocky Mountain Forest and Range Experiment Station

ABSTRACT

Chaparral species that sprout appeared little changed after 47 years though all stems tagged in 1920 were dead. Non-sprouting species had died but were usually replaced by nearby seedlings or by layering.

KEY WORDS *Quercus dumosa*, *Ceanothus greggii*, *Rhus trilobata*, *Arctostaphylos pungens*, *Nolina microcarpa*, *Mimosa biuncifera*, chaparral.

USDA Forest Service
Research Paper RM-69

May 1971

Chaparral: 47 Years Later

by

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[1]Central headquarters maintained at Fort Collins, in cooperation with Colorado State University; author is located at Flagstaff, in cooperation with Northern Arizona University.

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47 Years Later

Floyd W. Pond

In 1920, a U.S. Forest Service research team fenced several small plots in central Arizona. One of these, an exclosure 130 by 330 feet in size, was located on what is now the Sierra Ancha Experimental Forest near Globe. This exclosure was located on fairly level terrain near the lower edge of the chaparral type (4,500 feet elevation).

Long-term weather records taken nearby show an average precipitation of 18 inches per year. Approximately one-half the rainfall is from summer thunderstorms (July to September) and the remainder is the result of winter storms. Two comparatively dry periods, May-June and October-November, separate the two precipitation periods. Temperatures rarely exceed 100° F. during the summer and may occasionally reach 10° F. during the winter. Snow may occur several times during winter but rarely remains on the ground for more than a day.

Soils on the area have been tentatively called Jayaar sandy loam and are formed from diabase parent material. These soils rarely show much horizon development and the unconsolidated mass of the soil mantle is frequently over 4 feet. However, numerous large boulders are present in the mantle or on the soil surface.

Immediately after fencing in 1920, individual plants of six chaparral species were tagged. Half the tagged plants of each species were inside the exclosure and the other half outside. Each plant was photographed and negatives deposited in the U.S. Forest Service photographic file, Washington, D. C. This plot with its records provided a rare opportunity to study life span and replacement of several chaparral shrub species.

Some tagged shrubs were rephotographed in 1927, some in 1935, and one shrub live oak in 1962. In 1967, photos were made of all shrubs for which early pictures were available. Several of the 1920 negatives had deteriorated and could not be used.

A general view of the northwest corner of the plot, taken in 1927, (1), showed little change in shrub cover during the 40 years when compared with the 1967 photo (2). Plants appeared a little larger but occupied essentially the same area.

1-1927

2-1967

SHRUB LIVE OAK

Quercus turbinella Greene

Individual shrub live oak plants tended to be tenacious. Only one of the eight plants tagged in 1920 (3) died during the 47-year interval; by 1967 the only visible evidence that an oak had once occupied the area (4) was the 2-inch stem on which the tag had been placed. Photos were not available for five other oaks, but tags were found on three of the five and healthy specimens occupied the sites of the other two. Two of the five can be seen in the lower right-hand corner of the general views, and appear much the same in both photos. Complete photographic records for one shrub live oak were available. This oak was a vigorous plant about 7 feet high in 1920 (5) and changed little by 1927 (6) or 1935 (7). By 1962 (8), many older, larger stems were dead including the tagged one. By 1967 (9), more deadwood was present, but young sprouts from the base were healthy.

3-1927

4-1967

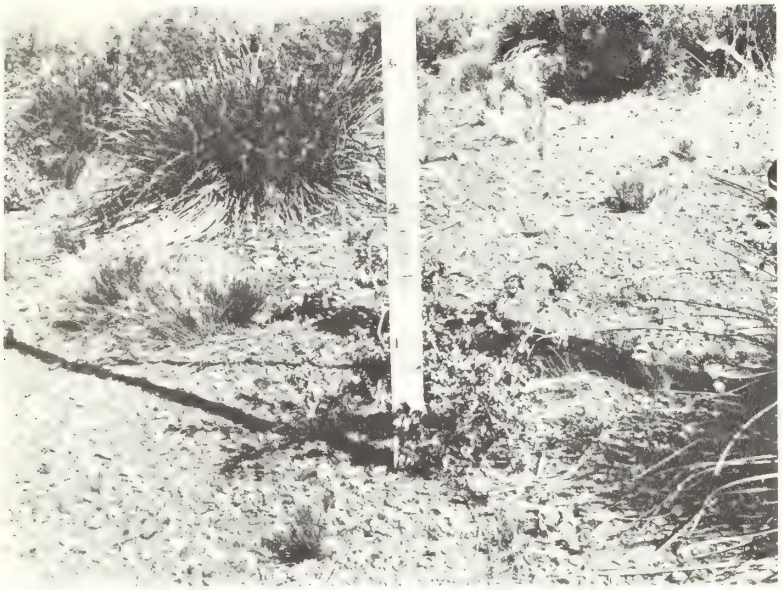
5-1920

6-1927

7-1935

8-1962

9-1967



10-1920

11-1927

12-1967

Photos of the remaining shrub live oak (none taken in 1935) show a plant less than 2 feet high in 1920 (10) and less than 3 feet tall in 1927 (11) or 1967 (12). The tag was on a dead stem less than 0.5 inch in diameter. During the 47 years the plant did not attain the compact, leafy appearance of a vigorous oak plant. Evidently the site was not conducive to good shrub live oak growth.

These photographic records as well as observations of other tagged oaks help demonstrate the tenacious quality of the species. Shrub live oak is known to sprout rapidly following fire and is not easily killed by application of most herbicides. Although one plant died during the 47-year interval, the remaining seven were comparatively healthy. All tags were found on dead stems, which indicates the overstory was replaced at least one time by sprouts. Also, protection did not enhance survival since the one dead plant was inside the exclosure.

13-1920

14-1927

DESERT CEANOTHUS

Ceanothus greggii A. Gray

Desert ceanothus plants were less tenacious than shrub live oak. Since this species seldom sprouts and depends on seedlings for replacement, its ability to compete may not be equivalent to that of prolific sprouters.

Photos for one of the four ceanothus were not available. The nearest living plant or skeleton to the proper location was over 30 feet away. Since dead ceanothus skeletons are persistent, the plant was probably dead prior to the 1935 observation.

A complete photo record was available for the other exclosed ceanothus. Observations without photography in 1962 indicated this plant was still vigorous after 42 years. Search for the tag in 1967, however, revealed a dead, tagged skeleton about 2 feet from the vigorous plant. This replacement plant likely had seeded within a few years after the 1935 observation since it was a fully mature specimen by 1962. The original plant was healthy, mature, and productive in 1920 (13). Some dead material was evident in 1927 (14) but the plant was still fairly vigorous in 1935 (15). The 1967 photo (16) shows only a dead stump with some fairly small twigs still attached. The presence of small twigs on the skeleton indicates recent death—probably shortly before the observation in 1962.

15-1935

16-1967

17-1920

18-1927

19-1967

20-1920

A third plant, located just outside the exclosure, was not found in 1962. Careful search in 1967 located the dead, uprooted stump with tag attached about 20 feet from the proper location. The 1920 photo (17) shows a vigorous shrub about 3.5 feet high. The plant was still vigorous in 1927 (18) but current growth was less obvious at this time. No photos were taken in 1935 and, from the appearance of the stump in 1967 (19), the plant could have been dead or near death at that time. Although this plant was not replaced by a seedling on the exact site, several vigorous young plants were found about 10 feet away.

The fourth ceanothus, also outside the exclosure, was not found in 1967. Neither living plants nor dead skeletons were found within 50 feet of the proper location. The plant was vigorous in 1920 (20), but some dead material was evident by 1927 (21). Since photos were not taken in 1935, the plant may have been dead at that time.

All four ceanothus failed to survive the 47-year span of time. From appearance of skeletons or lack of skeletons, three of the four likely died prior to 1940. Other observations within the type indicate ceanothus is shorter lived than the sprouting species. Since vigorous plants were found near two of the four locations, some replacement by seedlings is indicated.

21-1927

SACAHUISTA

Nolina microcarpa Wats.

Two sacahuista were tagged in 1920. Old photos of the exclosed plant were not available, but the iron stake with attached tag used to mark this plant was found and sacahuista were growing no more than 5 feet away. The original plant was completely dead and missing.

The 1920 photo of the sacahuista outside the exclosure showed a plant 2 feet high (27). By 1927 the plant, along with others in the vicinity, had been closely grazed by livestock or rodents, and did not appear vigorous (28). Photos were not taken in 1935, and in 1967 the plant had completely disappeared although several vigorous plants were present in the near vicinity (29).

Sacahuista is most common in the lower (4,000 to 5,000 feet elevation) part of the chaparral type, and is often used by cattle or wildlife. It appears that individual plants may not live longer that 50 years since both the tagged plants were dead. Also, replacement in nearby areas seems to be no problem since vigorous plants were found in both areas.

27-1920

28-1927

29-1967

WAIT-A-BIT

Mimosa biuncifera **Benth.**

Early photos of the two tagged plants of this universally disliked species were not available. Although living plants of this species occupied both sites, tags could not be found. Stems of wait-a-bit seldom get large so the tagged stems could have died and the tags buried or removed from the area.

The tenacious sprouting nature of this shrub is well known. Doubtless, the two plants seen in 1967 were those tagged in 1920. This plant is very resistant to burning, herbicide treatment, or grazing. An area once occupied by wait-a-bit will likely be dominated by the species for many years. Wait-a-bit is restricted to the lower fringe of the chaparral type.

Pond, Floyd W.
1971. Chaparral: 47 years later. USDA Forest Serv. Res. Pap. RM-69, 11 p., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

Chaparral species that sprout appeared little changed after 47 years though all stems tagged in 1920 were dead. Nonsprouting species had died but were usually replaced by nearby seedlings or by layering.

KEY WORDS: *Quercus turbinella*, *Ceanothus greggii*, *Rhus trilobata*, *Arctostaphylos pungens*, *Nolina microcarpa*, *Mimosa biuncifera*, chaparral.

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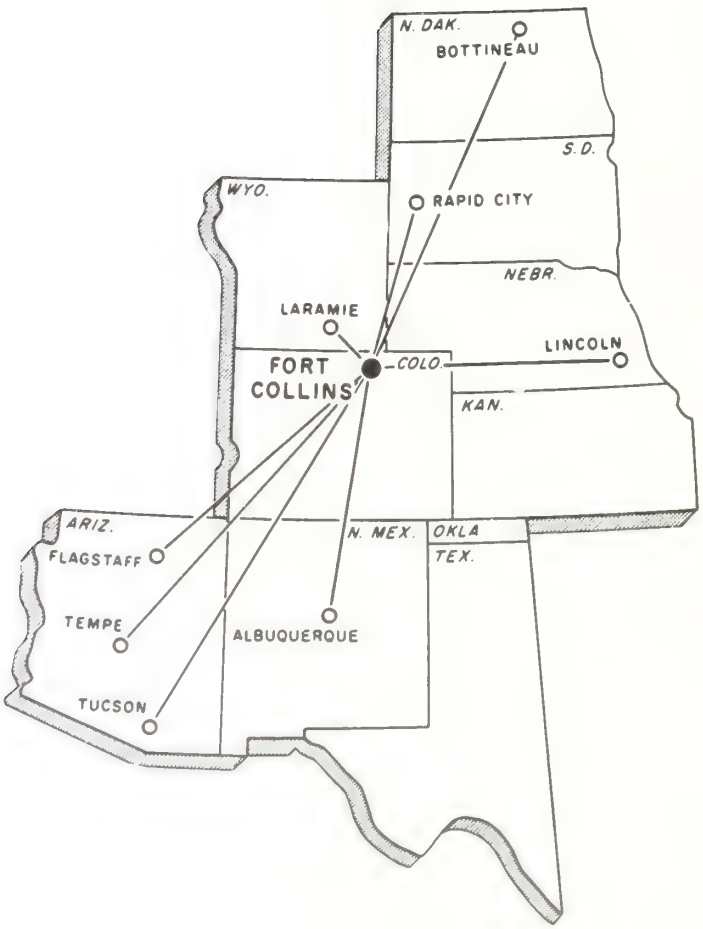
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Research Paper RM-70
June 1971

Rocky Mountain Forest and
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Forest Service
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Frequency of STEM FEATURES AFFECTING QUALITY in ARIZONA MIXED CONIFERS

by Robert S. Embry
and Gerald J. Gottfried

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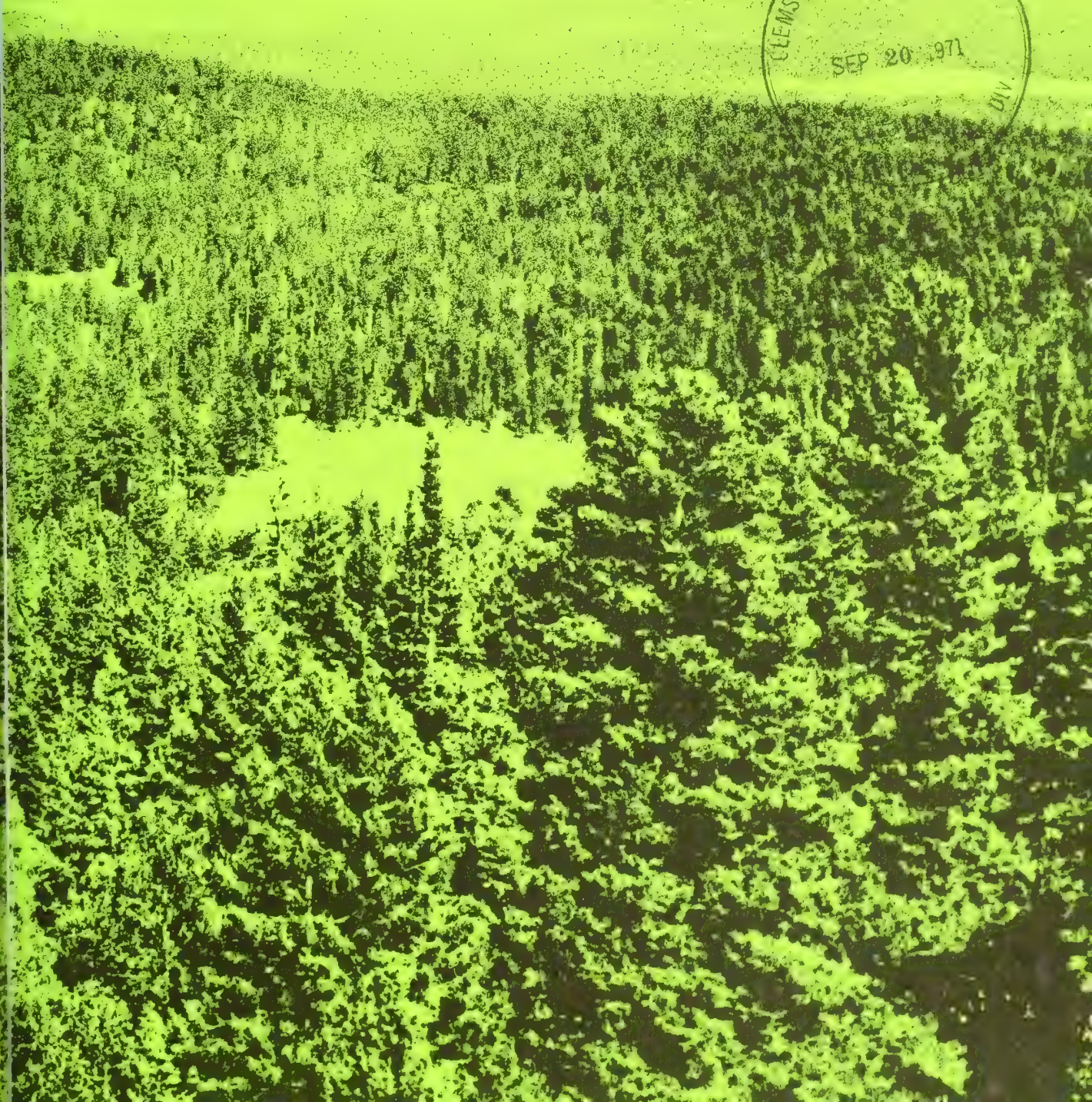

ABSTRACT

Frequency of occurrence of visual stem features that affect end-product quality and yield is presented by species and size-class. Data were obtained in an overstory inventory of 1,800 acres of mixed conifer forests in the Arizona White Mountains.

Key words: Timber quality, mixed conifer forests.

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Frequency of Stem Features Affecting Quality in Arizona Mixed Conifers

by

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[1]Central headquarters maintained at Fort Collins in cooperation with Colorado State University; Embry is located at Flagstaff in cooperation with Northern Arizona University, Gottfried is located at Tempe in cooperation with Arizona State University.

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Frequency of Stem Features Affecting Quality in Arizona Mixed Conifers

Robert S. Embry and Gerald J. Gottfried

Mixed conifer stands occupy approximately 300,000 acres in Arizona. These are mostly uncut, all-aged stands on some of the most productive forest sites in the State. Seven coniferous and a deciduous species, in a wide variety of mixtures, characterize the mixed conifer forests (fig. 1):

- Engelmann spruce (Picea engelmannii Parry)
- Blue spruce (Picea pungens Engelm.)
- Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco)
- White fir (Abies concolor (Gord. and Glend.) Lindl.)
- Corkbark fir (Abies lasiocarpa var. arizonica (Merriam) Lemm.)[2]
- Ponderosa pine (Pinus ponderosa Laws.)
- Southwestern white pine (Pinus strobiformis Engelm.)
- Quaking aspen (Populus tremuloides Michx.)

Significant timber harvesting from these mixed stands began in 1966 on the Apache National Forest. Since then, cutting has increased annually. Stumpage values have also increased since 1966. Presently, saw logs are the primary product harvested, with a minor volume being taken for pulpwood and mine timbers.

Need for Basic Timber Quality Information

With the continuing trend toward new products, new conversion methods, and more diversified opera-

[2] *On the Kaibab Plateau, corkbark fir is replaced by subalpine fir (Abies lasiocarpa var. lasiocarpa (Hook.) Nutt.)*

Figure 1.-- Stands such as this are characteristic of the mixed conifer forests in Arizona.

tions, the old saw-log concept of timber quality is no longer adequate. Standing timber must be described in terms of suitability for a range of potential products. Forest inventory information must categorize the tree resource in terms of physical stem characteristics that determine its suitability for specific products.

Stem quality for most primary products is largely determined by the same few features—diameter, height, sweep, crook, fork, and aggregate knot or limb characteristics. Suitability of the timber for a wide variety of products can be estimated if the size of timber and sufficient information about the frequency of occurrence of these characteristics is known. This paper reports the results of an inventory designed to produce this stem-quality data.

Mixed Conifer Area Studied

The area studied (fig. 2) consists of four watersheds totaling approximately 1,800 acres within the Black River Barometer Watershed in east-central Arizona. The area is typical of the uncut mixed conifer stands in Arizona found at elevations of 8,400 to 9,300 feet. Current gross sawtimber volumes average about 16,000 board feet per acre.

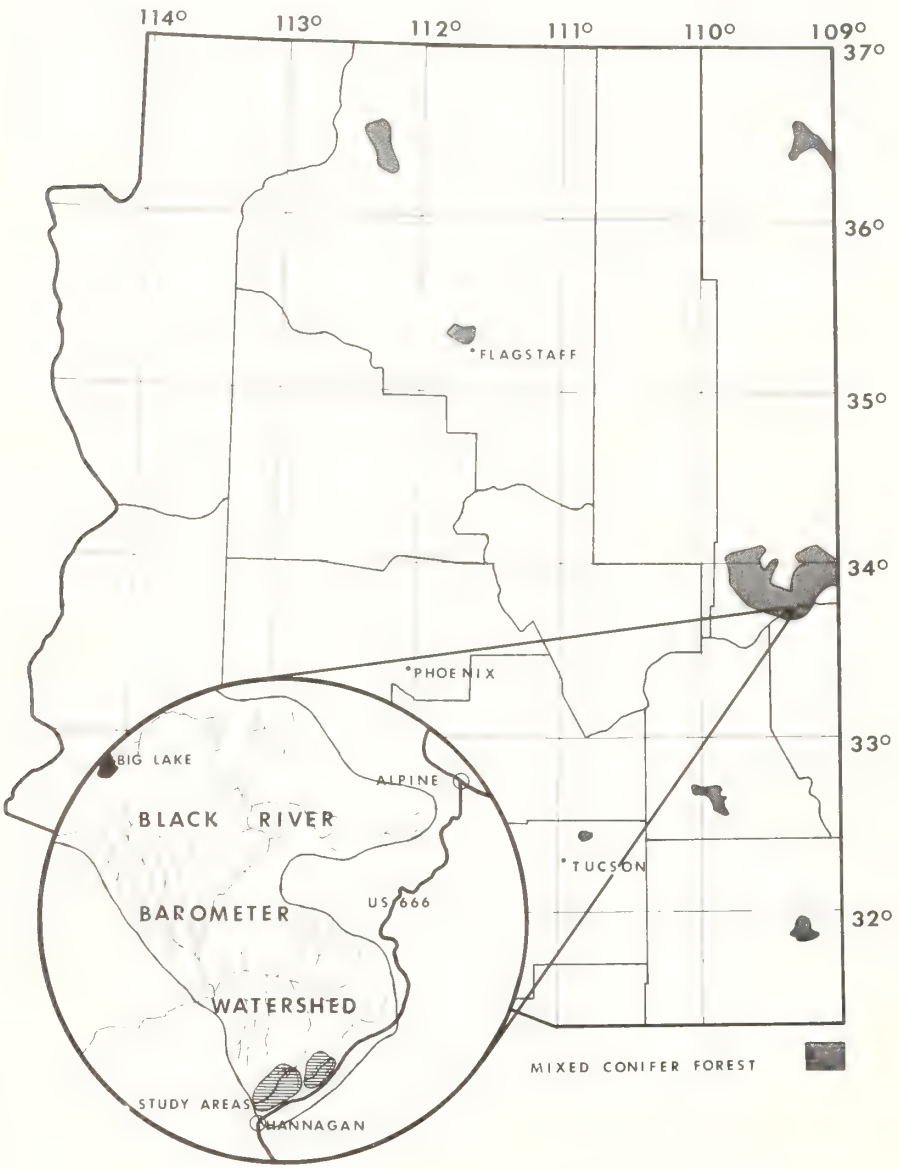

Figure 2.--
The study area, part of the Black River Barometer Watershed, is located on the Apache National Forest in east-central Arizona.

Measuring Stem Quality Characteristics

An overstory inventory of each watershed was made according to methods developed by Ffolliott and Worley.[3] Stem quality features were obtained from standing timber as described by Barger and Ffolliott.[4] The inventory method was designed to provide for systematic observation and measurement of all major visual stem characteristics related to primary product quality. The frequency of occurrence of observed features may be computed from data collected by this method.

Point-sampling techniques were used to select sample trees. A total of 556 permanent sample points were located on the pilot watersheds. Trees 7.0 inches d.b.h. and larger were selected at each sample point with an angle gage corresponding to a basal area factor of 25. A total of 3,336 trees were selected for observation and measurement (table 1).

[3] *Ffolliott, Peter F., and David P. Worley. An inventory system for multiple use evaluations. U. S. Forest Serv. Res. Pap. RM-17, 15 p., 1965. Rocky Mt. Forest and Range Exp. Sta., Ft. Collins, Colo.*

[4] *Barger, Roland L., and Peter F. Ffolliott. Evaluating product potential in standing timber. USDA Forest Serv. Res. Pap. RM-57, 20 p., 1970. Rocky Mt. Forest and Range Exp. Sta., Ft. Collins, Colo.*

Visual stem features that affect product quality and yield were recorded for each sample tree. Features observed and measured included (1) tree size—diameter and height; (2) stem form features of sweep, crook, fork, and lean; (3) injury features; and (4) log knot configurations in sawtimber stems.

Frequency of Stem Quality Features

All trees selected with the 25 BAF gage were aggregated by size class and species. Trees exhibiting the observed stem-quality features were summarized in a similar manner. Frequency of occurrence was indicated by the proportion of trees with a specific feature compared to the total number of selected trees. A species frequency-of-occurrence table was constructed for each observed quality feature. To facilitate presentation, the frequency-of-occurrence tables for individual stem features have been converted to bar graphs. The importance of each stem form and injury feature, how it affects quality, and data on its frequency of occurrence is presented by size class and species.

Trees were grouped into four major size classes:

Size class	D.b.h. range (Inches)
Pole	7.0 - 10.9
Small sawtimber	11.0 - 16.9
Medium sawtimber	17.0 - 22.9
Large sawtimber	23.0 plus

Table 1.--Distribution of trees 7.0 inches d.b.h. and over on the mixed conifer study area, east-central Arizona

Species	Trees	Proportion of total trees	Sample points on which species occurred[1]	Frequency of occurrence[1]	Average of trees per acre
	Number	Percent	Number	Percent	Number
Engelmann spruce	467	14	194	35	24.6
Blue spruce	48	1	24	4	2.2
Douglas-fir	1060	32	389	70	35.4
White fir	490	15	213	38	14.8
Corkbark fir	111	3	64	12	7.0
Ponderosa pine	500	15	227	41	12.1
Southwestern white pine	186	6	133	24	7.4
Quaking aspen	474	14	178	32	37.1

[1] Based on a total of 556 permanent sample points.

Stem Form Features

Irregular form features in the merchantable stem can substantially influence product potential. Sweep, crook, lean, and fork are particularly important determinants of volume and quality of timber for specific end uses or products. Occurrence of these stem form features is presented in figures 3 through 15.

Observations of multiple crook—more than a single crook in the merchantable stem—were recorded on two of the four watersheds inventoried (fig. 8). A total of 247 permanent sample points were involved in this additional stem feature sampling.

SWEEP.--Recorded as:

1. Minor--less than 1/3 d.b.h. deviation in straightness.
2. Major--1/3 d.b.h. or more deviation in straightness.

Sweep reduces the usable volume of sawtimber stems, and limits the use of stems as commercial poles. Use for sawn structural members may be limited by grain that has too great a slope. Sweep may not lower recovery from pulpwood stems, but does reduce the amount of solid wood per cord.

Figure 3.--Sweep is defined as a gradual bend in the merchantable bole.

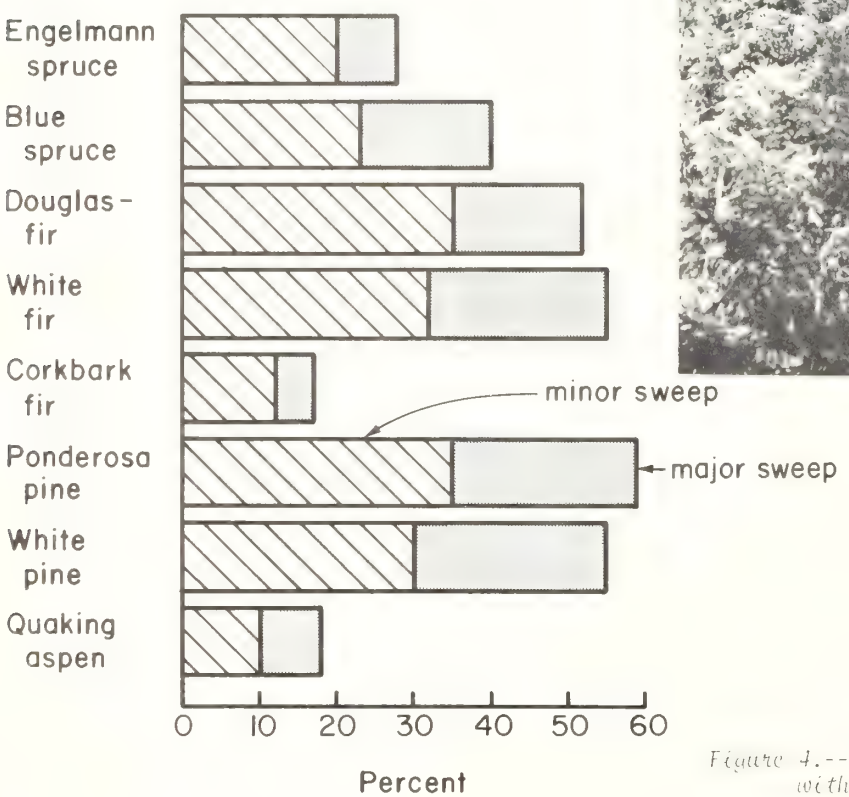

Figure 4.--Percentage of all sample trees with minor or major sweep.

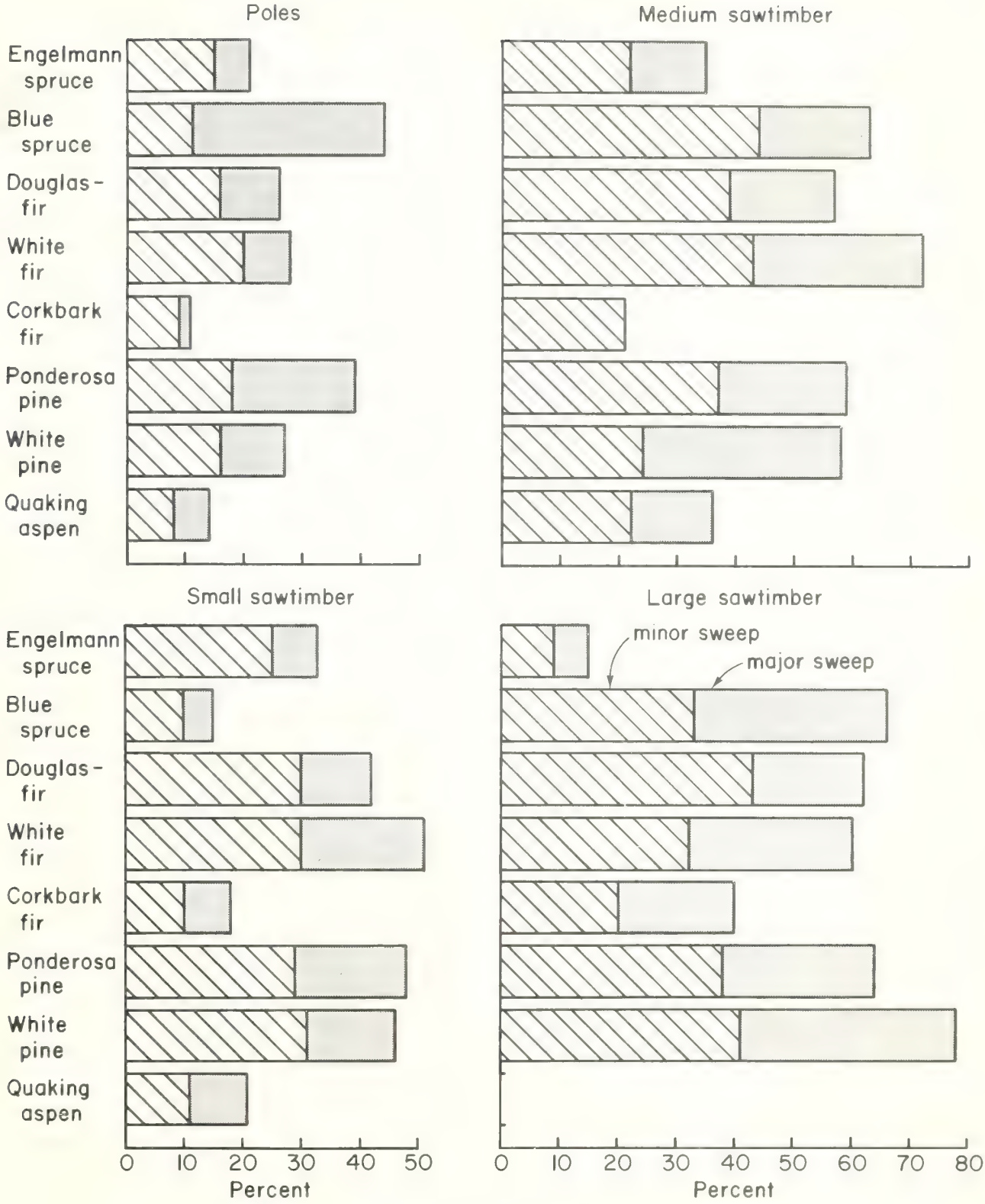

Figure 5.--Percentage of sample trees in four size-classes with minor or major sweep.

CROOK:--Recorded as:

1. Minor--less than ½ mean diameter deviation in straightness within a section 5 feet or less in length.
2. Major--½ mean diameter or more deviation in straightness within a section 5 feet or less in length.

Crook may reduce or limit the suitability of the merchantable stem for products such as poles. Stems with crook may have short grain or grain that has a greater slope than is permitted in many sawn structural members. Net volume may also be reduced.

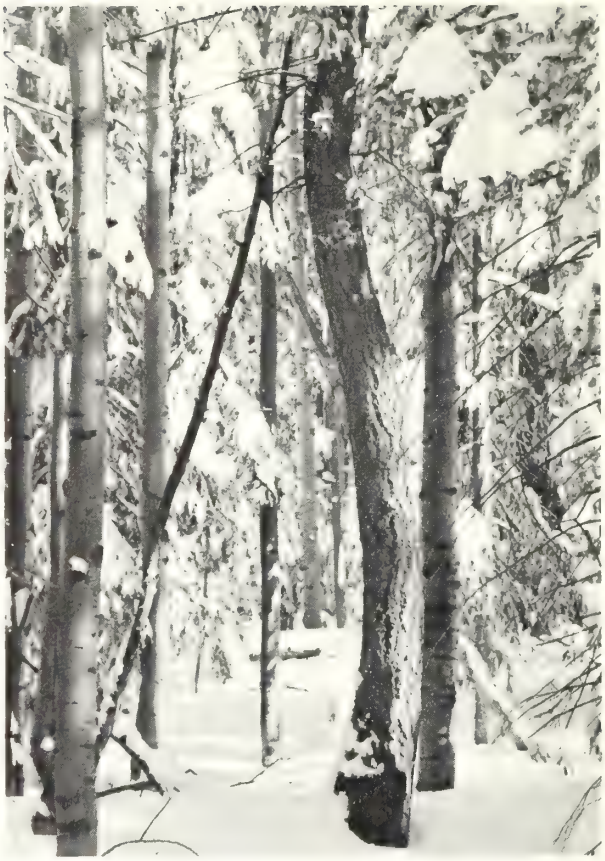

Figure 6.--Crook is defined as an abrupt bend in the merchantable stem.

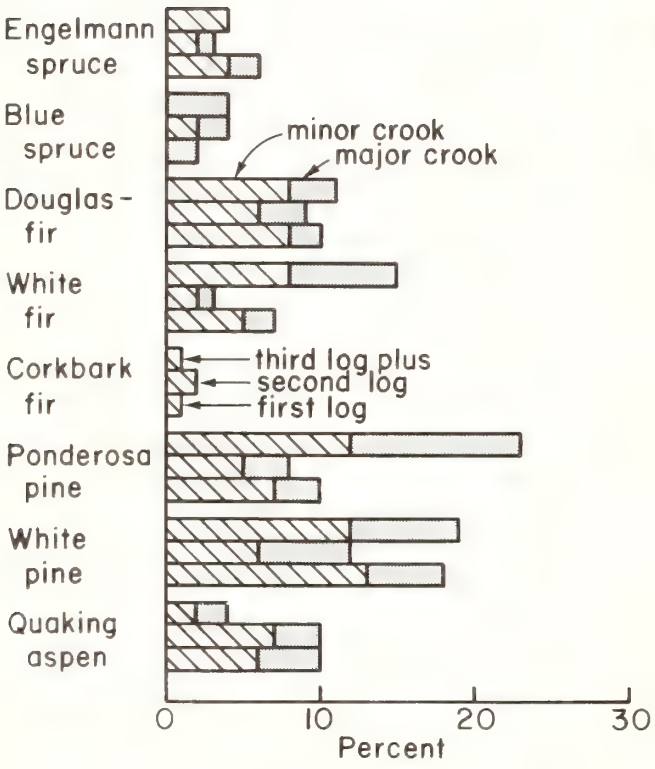

Figure 7.--Percentage of all sample trees with minor or major crook.

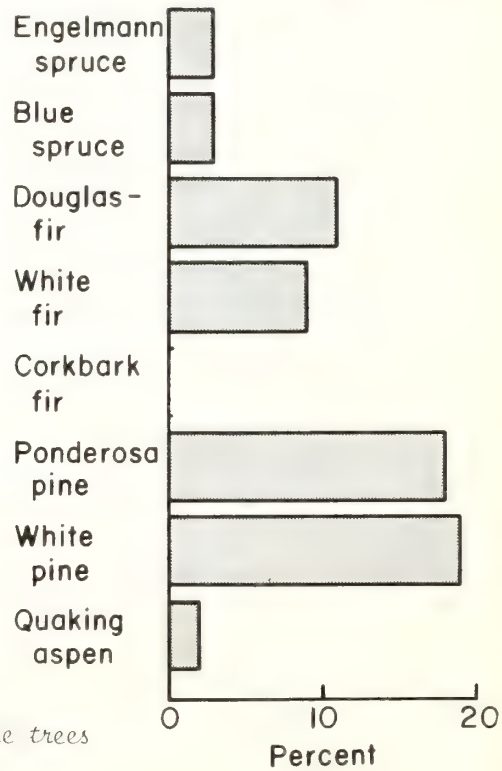

Figure 8.--Percentage of sample trees with multiple crooks.

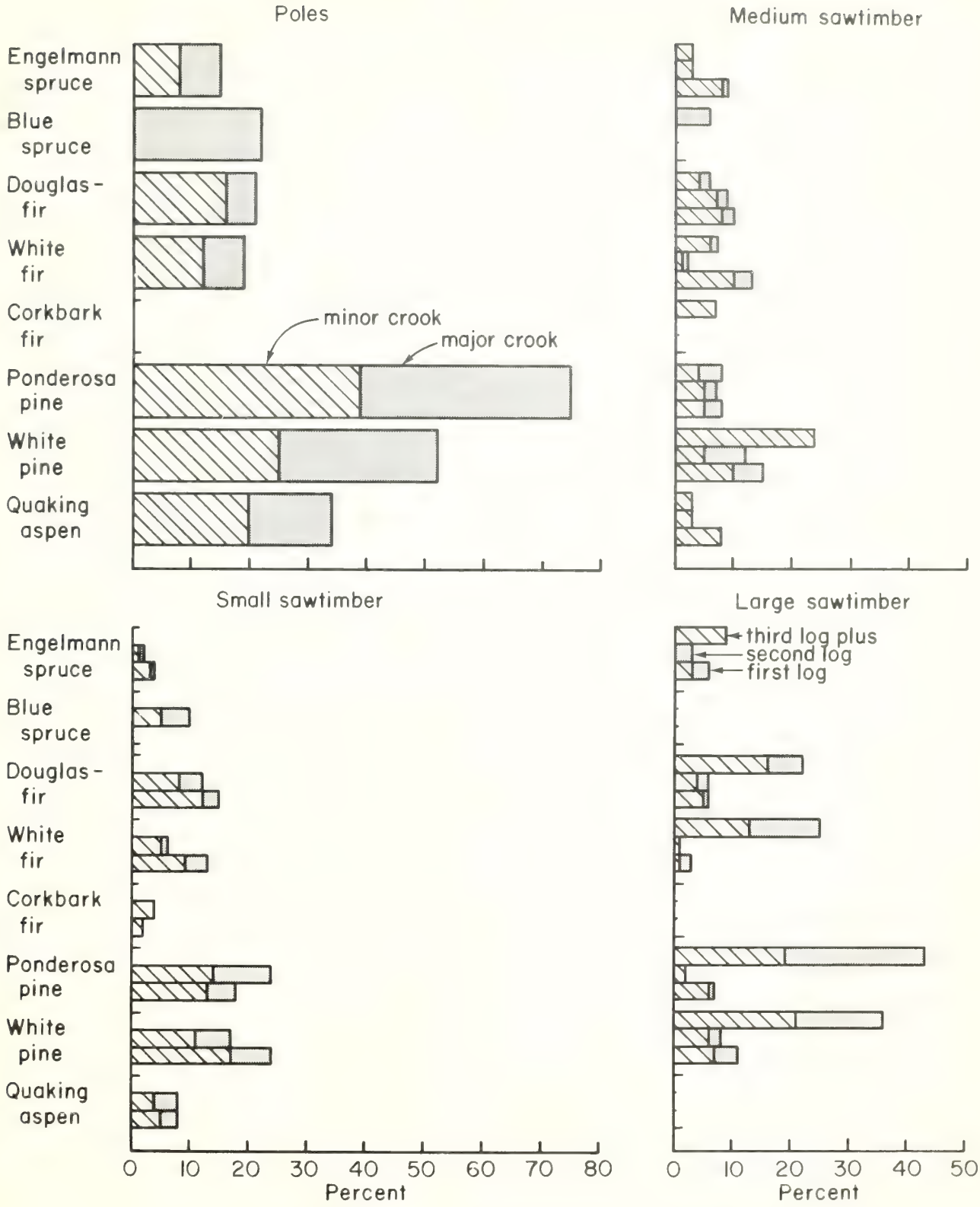

Figure 9.--Percentage of sample trees in four size classes with minor or major crook.

LEAN:--Recorded as degree of lean, to the nearest 5 degrees.

Lean is an important form characteristic because of the development of compression wood in leaning boles. According to Pillow and Luxford[5] compression wood in coniferous species is usually found in stems with 5 degrees or more of lean.

[5] *Pillow, M. Y., and R. F. Luxford. Structure, occurrence and properties of compression wood. U. S. Dep. Agr. Tech. Bull. 546, 32 p., 1937.*

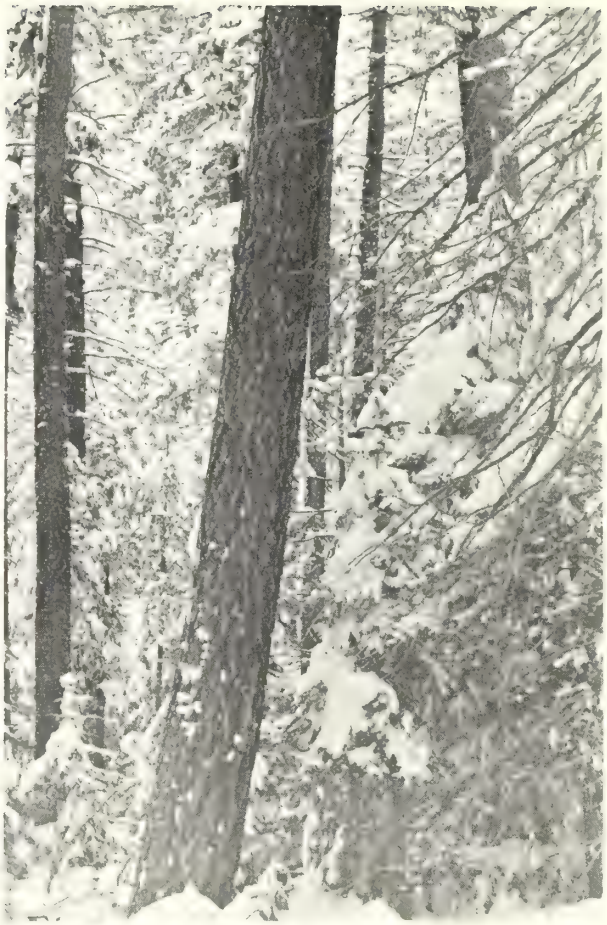

Figure 10.--Lean is defined as the deviation of the merchantable stem from vertical.

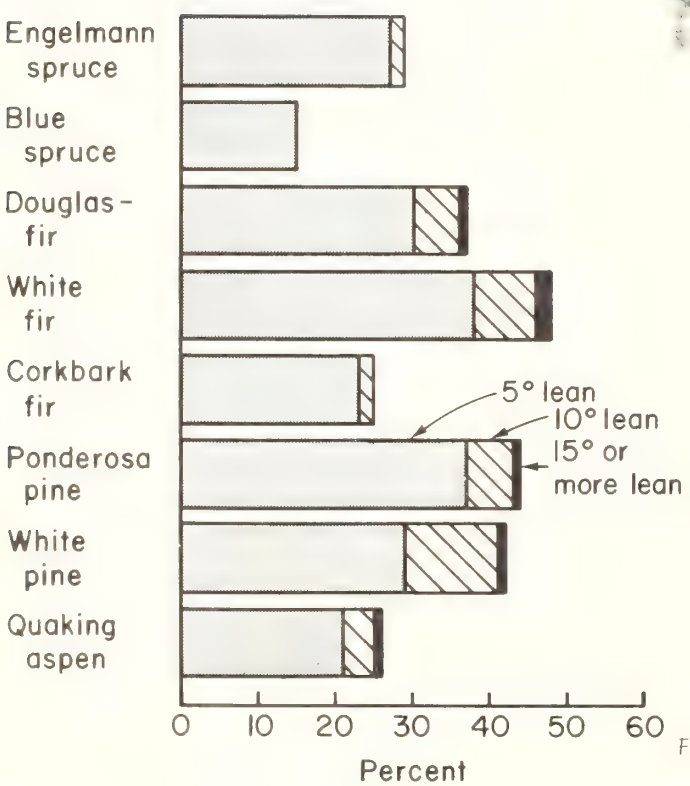

Figure 11.--Percentage of all sample trees with lean of 5°, 10°, or 15° or more.

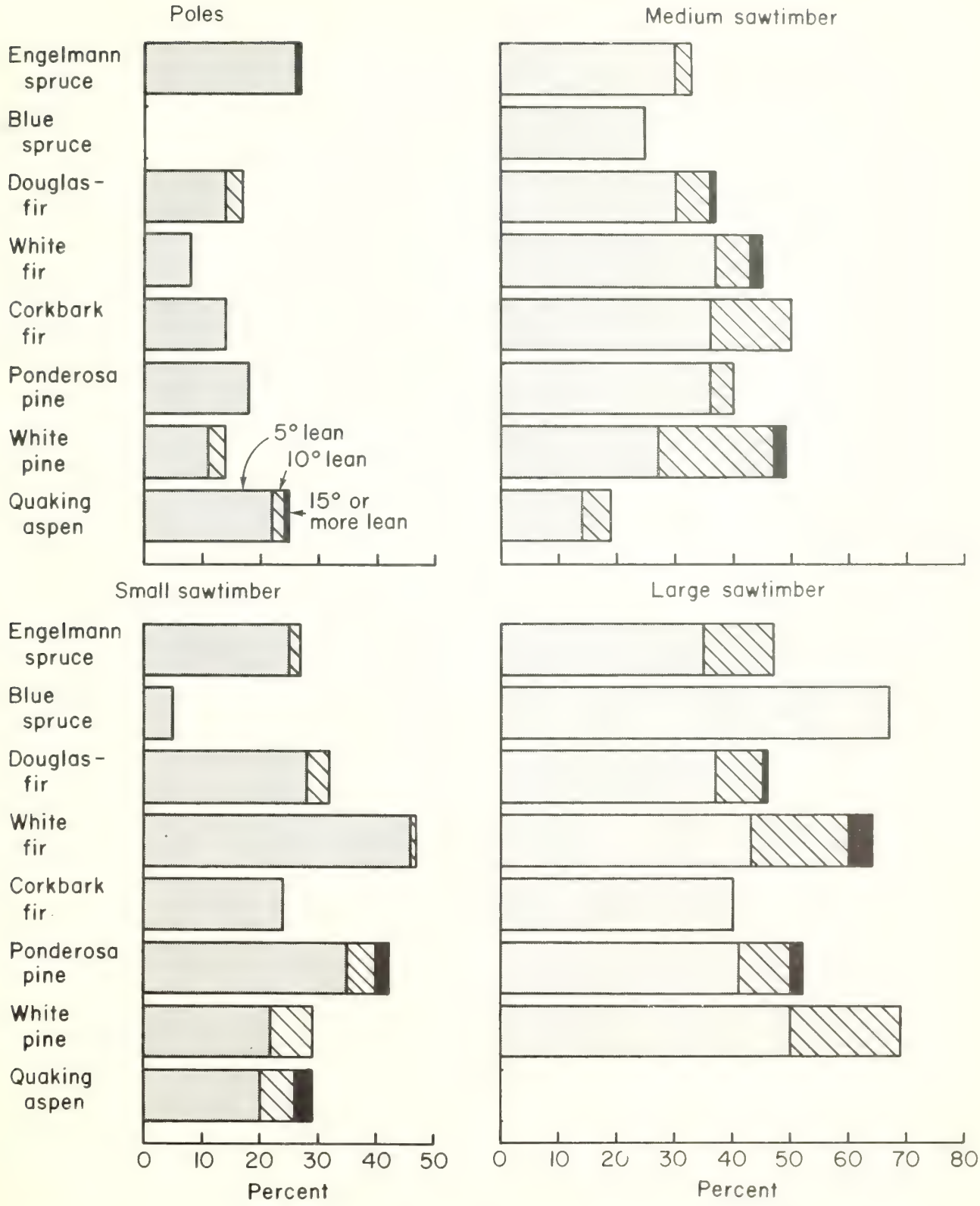

Figure 12.--Percentage of sample trees in four size-classes with lean of 5°, 10°, or 15° or more.

FORK:--Recorded as location of fork in stem, to nearest half-log.

The length of net scale of products obtained is limited by forking in the merchantable stem. The quality of adjacent material may also be lowered by the distorted grain accompanying a fork.

Figure 13.--
Fork is defined as a point of division of the merchantable stem.

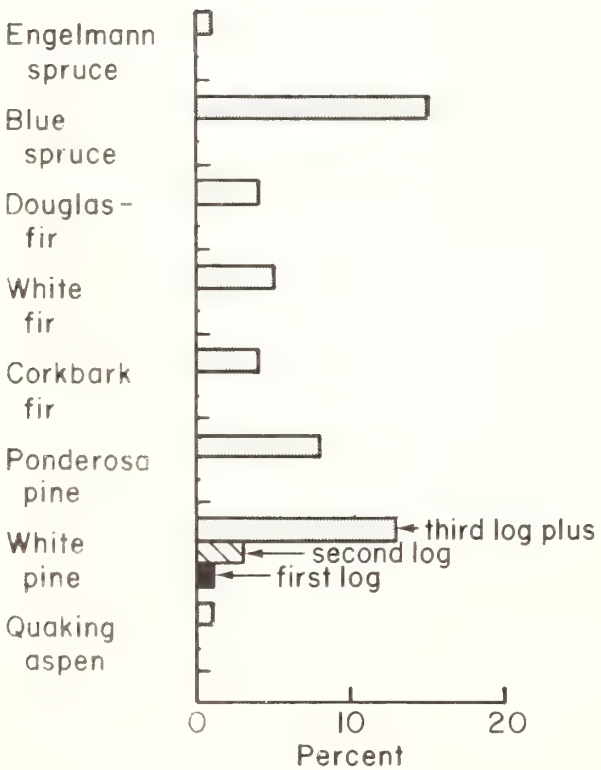

Figure 14.--Percentage of all sample trees with forked merchantable stems.

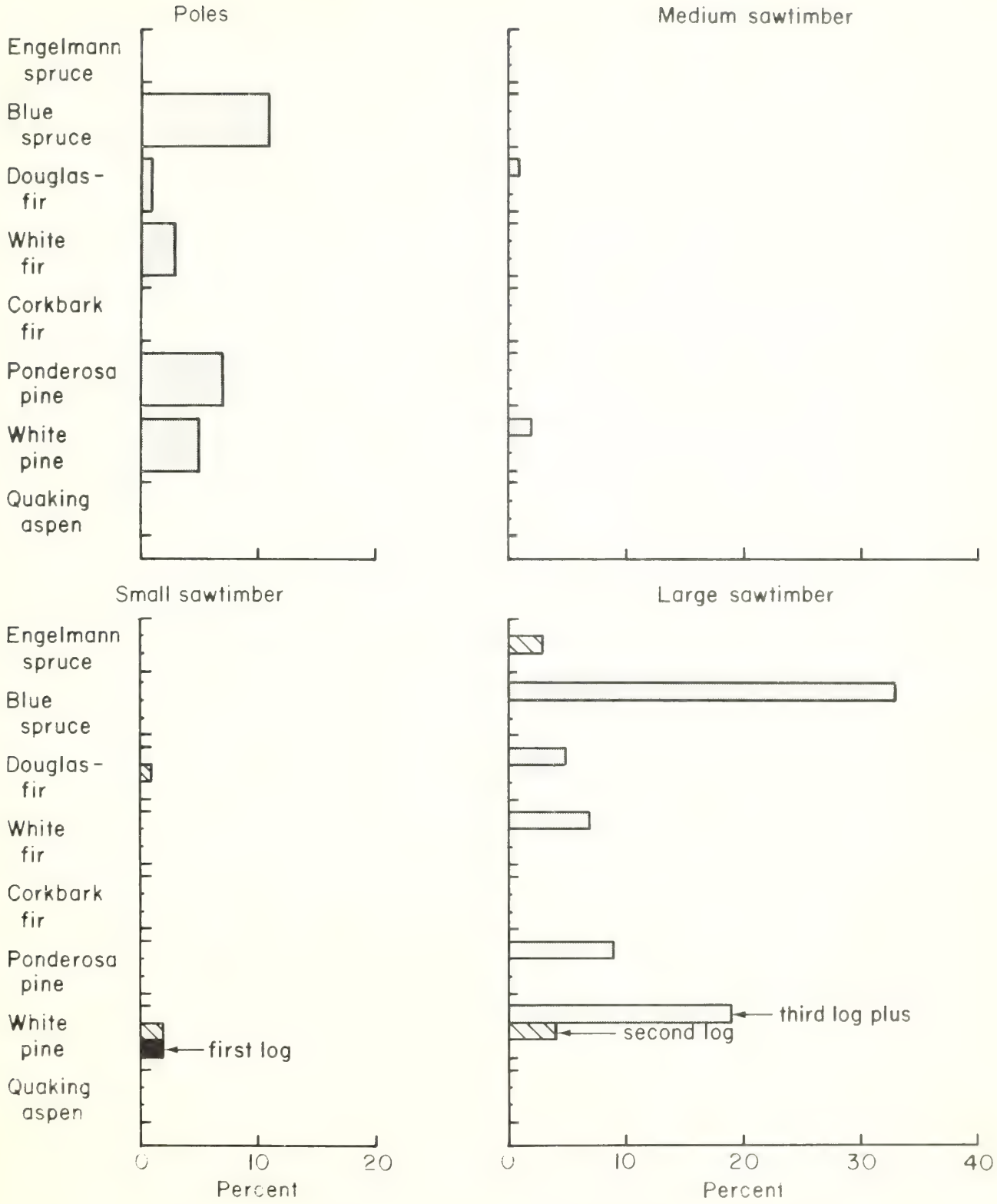

FIGURE 15.—Percentage of sample trees in four size classes with listed net board-foot sizes.

Injury Features

Injuries can reduce the usable volume of the merchantable stem. Two of the more common injuries in standing timber are basal scars and lightning scars. Dead and broken tops are also considered injuries. Top damage is primarily attributable to lightning in the larger size classes, while snow breakage and porcupines may account for a substantial portion in the smaller size classes. Dead tops may also be caused by severe mistletoe infection.

Injury features are further described in figures 16 through 21.

SCAR:--Recorded as:

1. Minor--less than ¼ bole circumference affected.
2. Major--¼ or more bole circumference affected. Essentially a spiral injury in the case of lightning scars.

Basal scars are usually confined to the first half-log. Lightning scars often affect the entire merchantable stem. Scars are considered as secondary grading defects in determining timber quality for various products.

Figure 16.--A scar is an opening in the bark exposing the underlying wood.

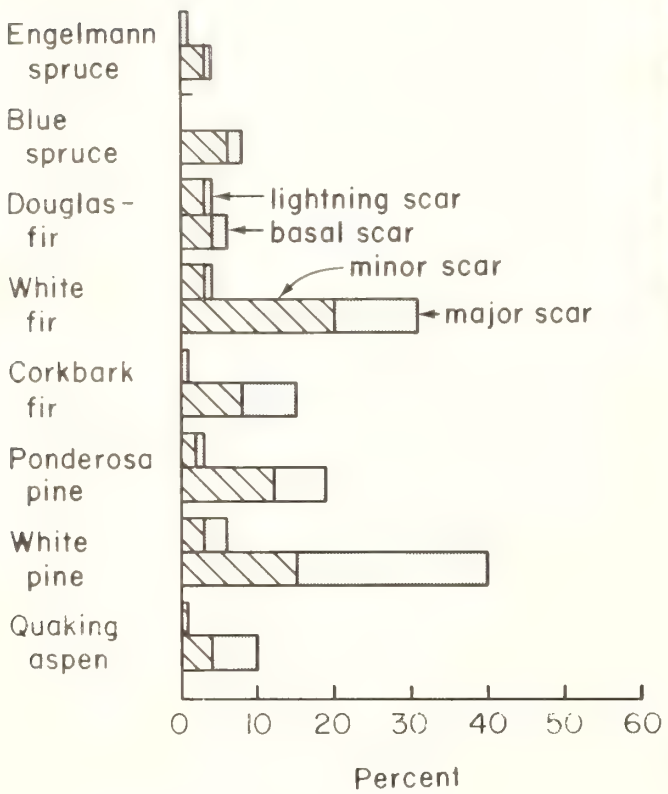

Figure 17. Percentage of all sample trees with basal or lightning scars.

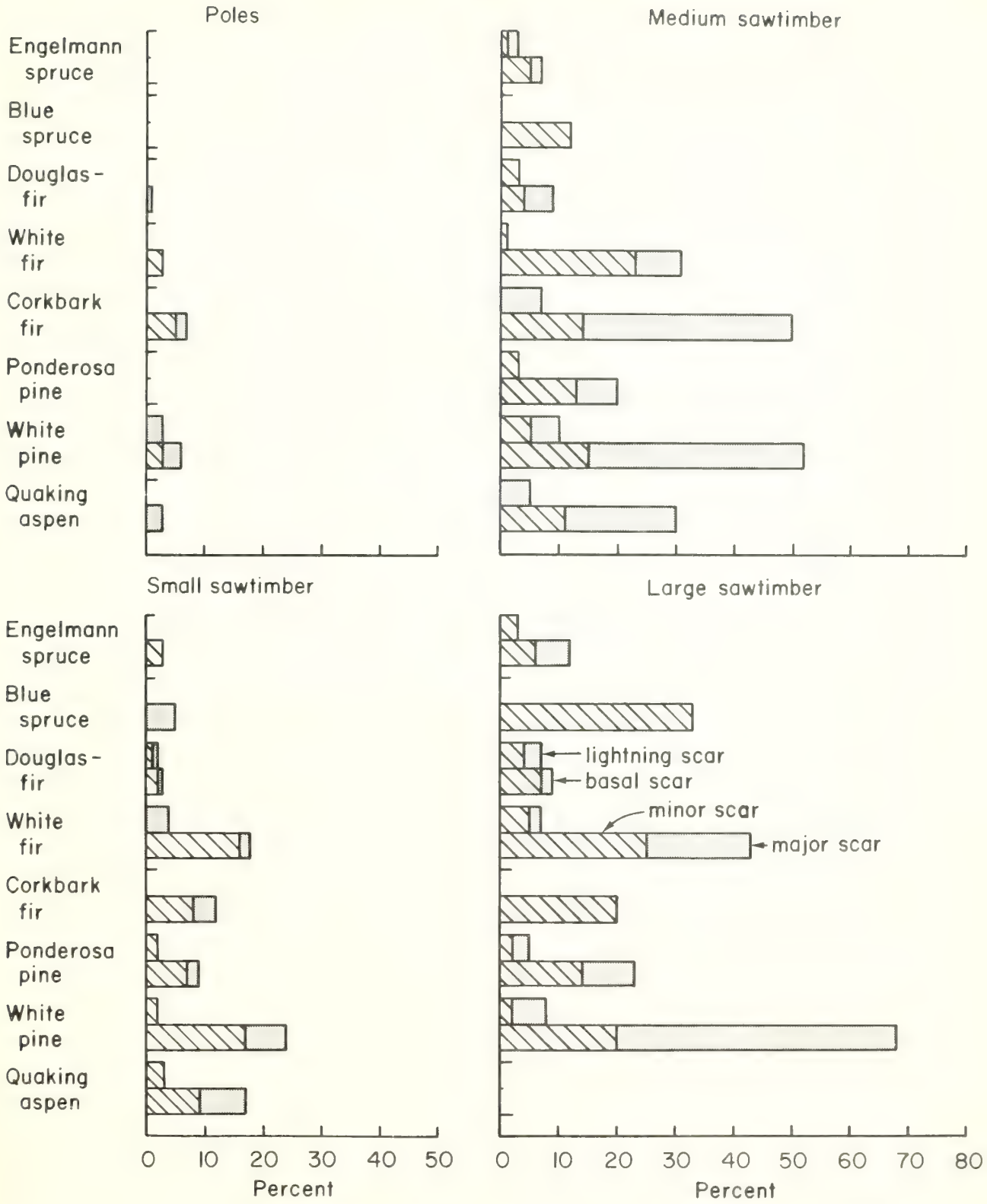

Figure 18.--Percentage of sample trees in four size-classes with basal or lightning scars.

TOP DAMAGE:--Recorded as:

1. Broken top.
2. Dead top.

Top damage is usually the result of lightning in the mixed conifer stands in the Southwest.

Figure 19.--Top damage is considered a mechanical stem injury.

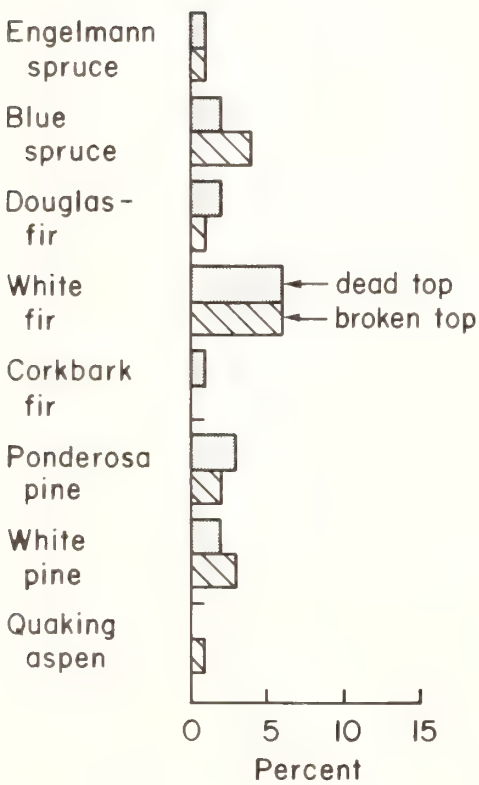

Figure 20.--Percentage of all sample trees with broken or dead tops.

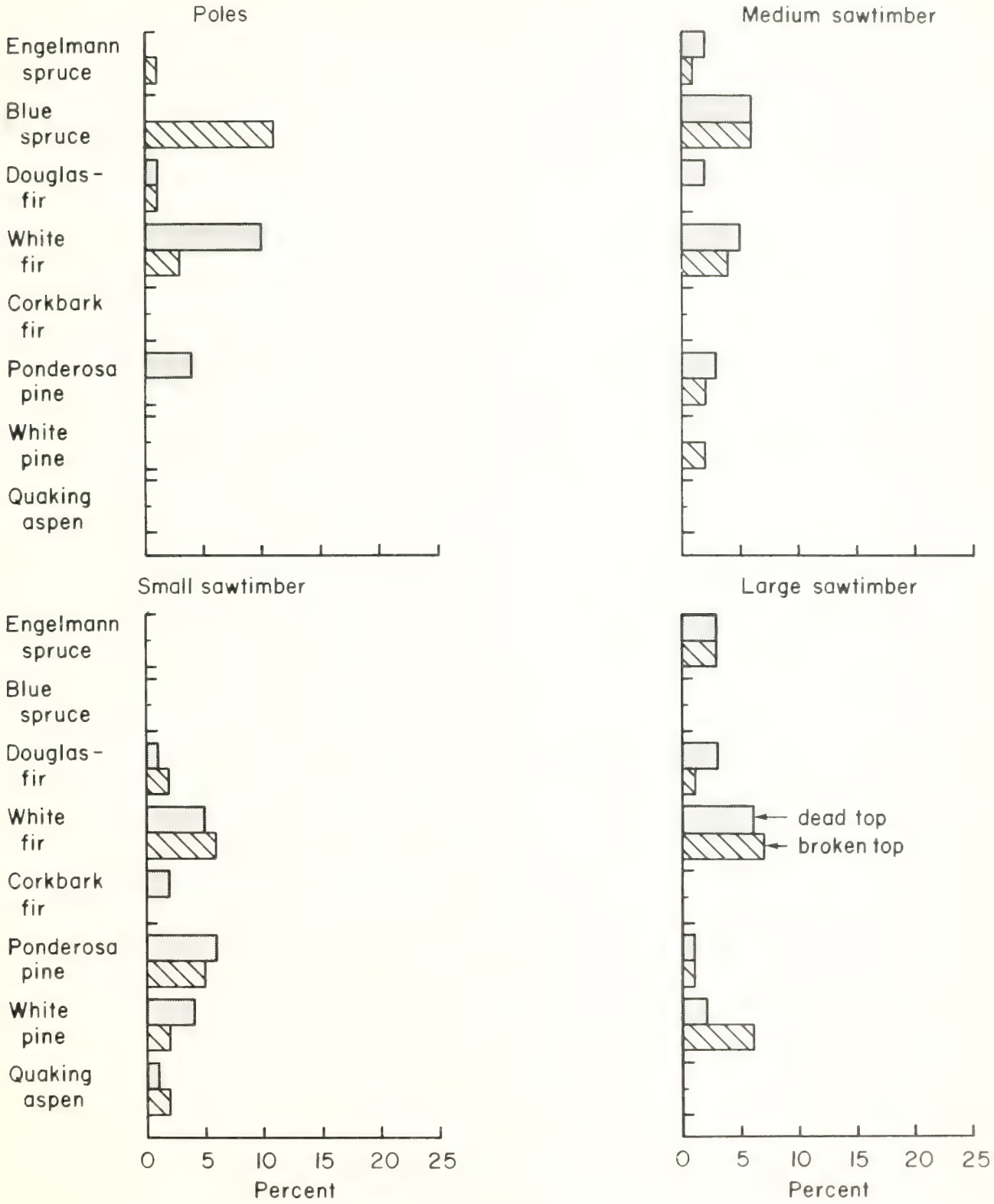

Figure 21.--Percentage of sample trees in four size-classes with broken or dead tops.

Log Knot Configurations

The distribution of clear surface area, and the number and size of log knots, are important indicators of primary product potential (fig. 22). The knot features of all coniferous sample trees 11.0 inches d.b.h. and larger were characterized in two ways: (1) presence of clear surface area in the first two 16-foot logs, and (2) number and size of knots in the first 16-foot log. Specific information recorded included:

A. Clear 8-foot faces (panels 8 feet by 1/4 bole circumference), recorded by position within each succeeding 8-foot stem section, to 32 feet height or to a 10-inch top diameter.

B. Log knots and knot indicators, recorded as:
   1. Number of knots in each full face of first 16-foot log.
   2. Diameter of largest knot in each log face, to nearest inch.
   3. Condition of largest knot in each log face (live or dead).

The occurrence of clear 8-foot faces in the butt 16-foot logs is presented in figure 23. Practically all clear faces observed were contained in the first 16-foot log of the larger size classes.

The number and size of log knots in the butt 16-foot logs are presented in figures 24 and 25, respectively.

Potential Use of Quality Information

Stem quality information forms the basis for most primary product grading systems. Such information provides a basis for inter-product comparisons and utilization decisions. The data presented here may be used to estimate the product potential of mixed conifer timber in Arizona. The extent to which a limiting stem defect may be expected to occur may also be estimated. Even if present grading systems should change, the stem quality information would continue to provide a basis for evaluating product potential without the need for an additional inventory.

Figure 22.--Clear log faces indicate suitability and high quality for most primary products.

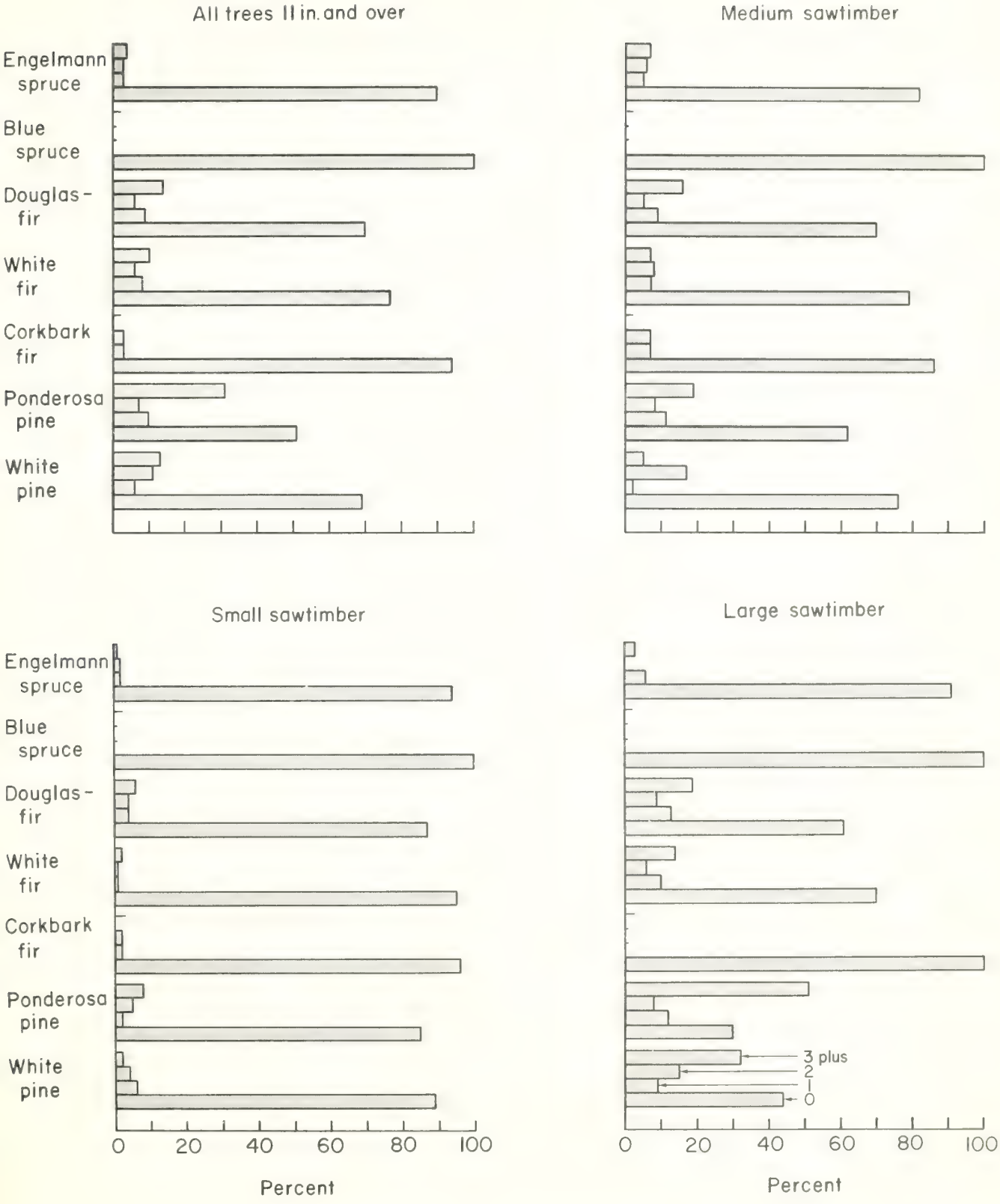

Figure 23.--Percentage of coniferous sawtimber stems with zero, one, two, and three or more clear faces in the butt 16-foot log.

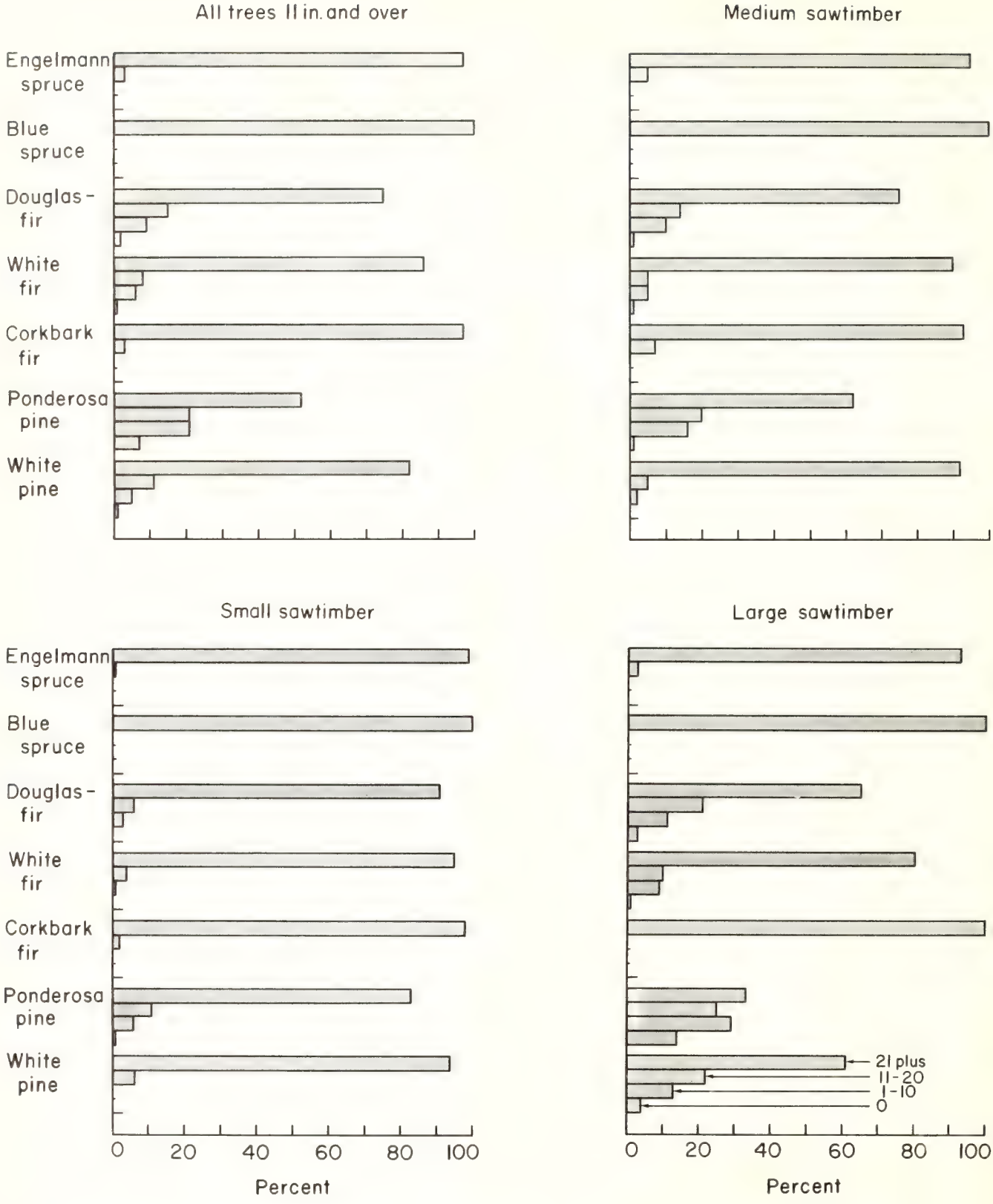

Figure 24.--Percentage of coniferous sawtimber trees with 0, 1 to 10, 11 to 20, and 21 or more knots in the butt 16-foot log.

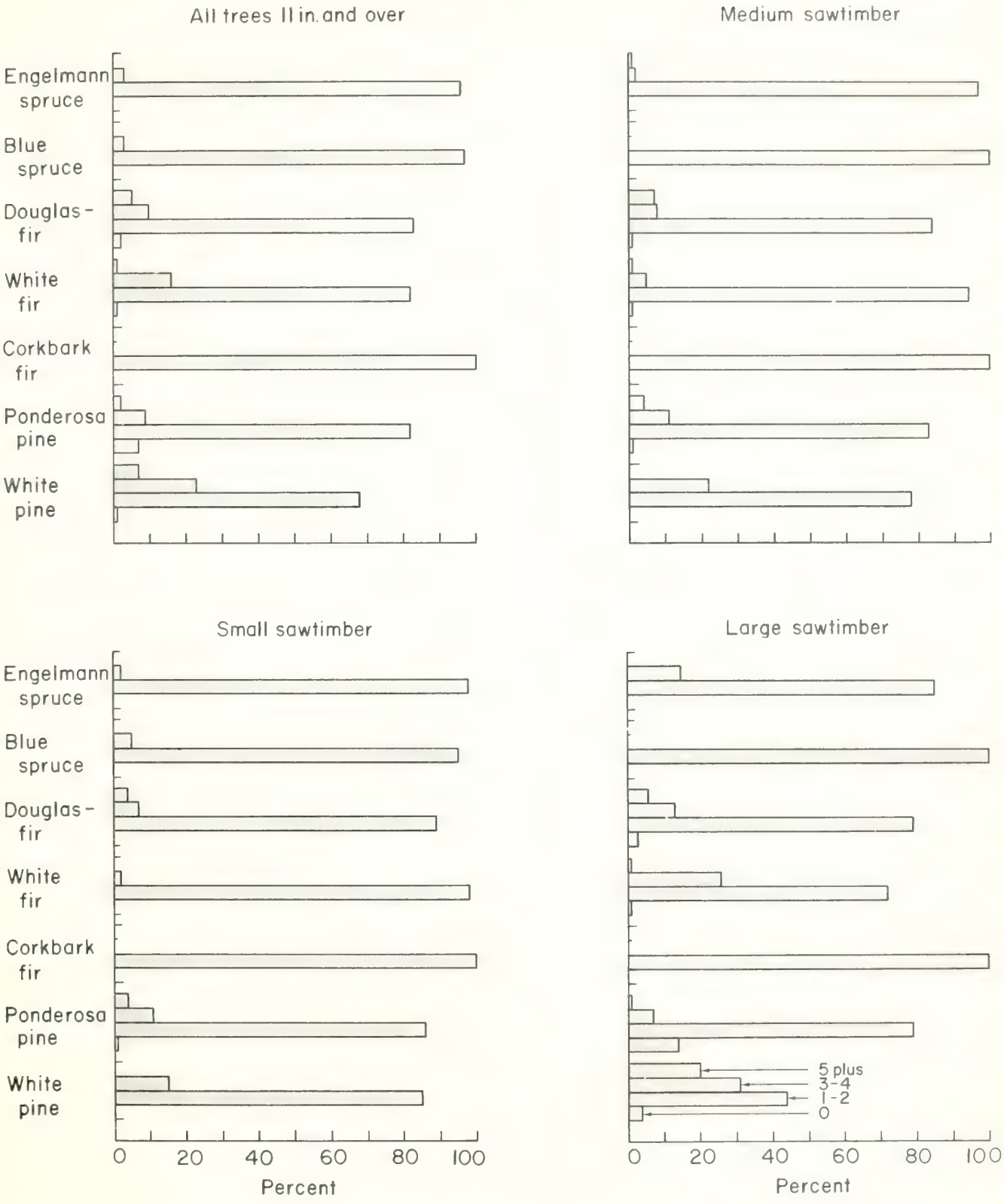

Figure 25.--Percentage of coniferous sawtimber stems in which the maximum knot size in the butt 16-foot log is 0, 1 to 2 inches, 3 to 4 inches, and 5 inches or more.

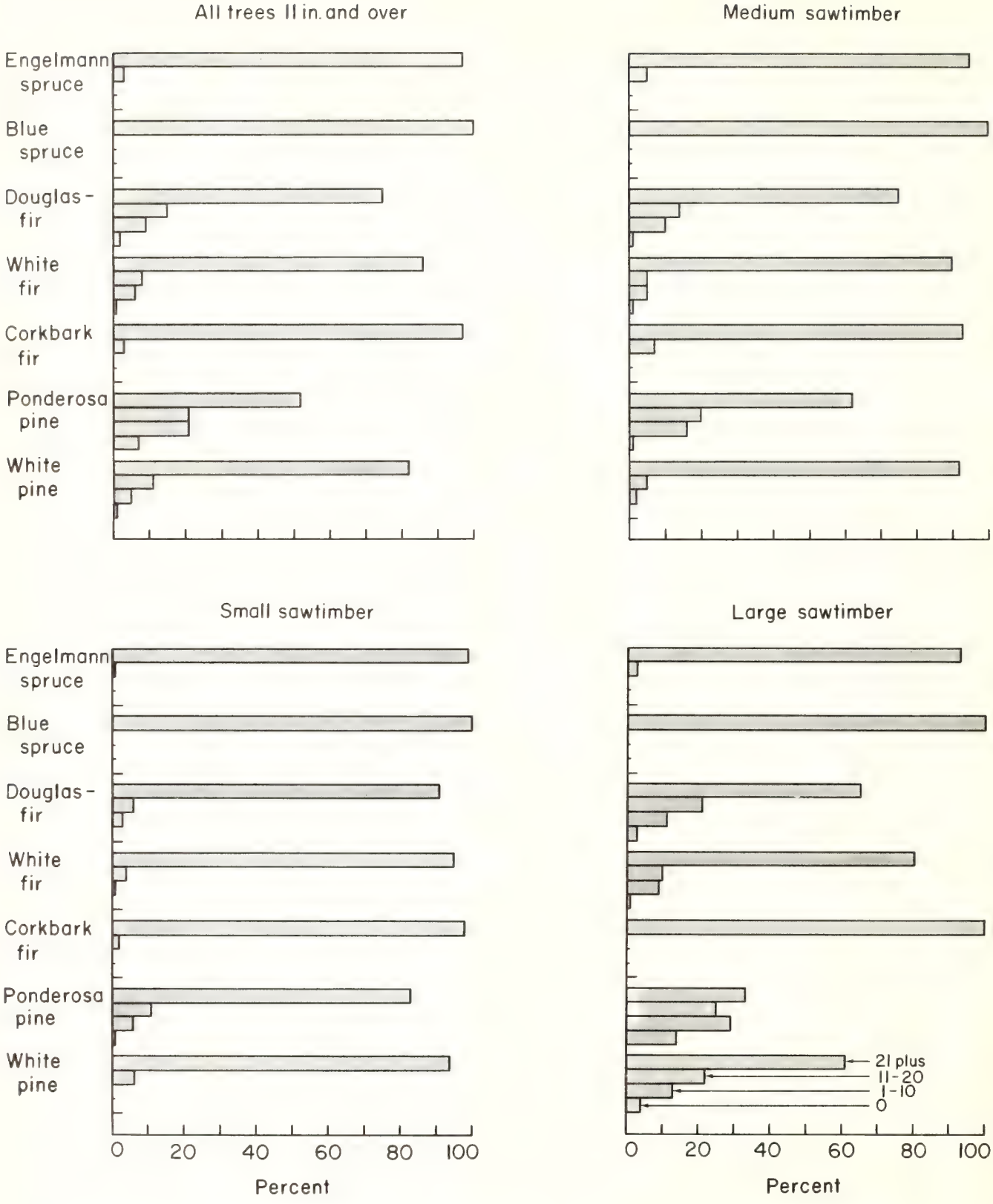

Figure 24.--Percentage of coniferous sawtimber trees with 0, 1 to 10, 11 to 20, and 21 or more knots in the butt 16-foot log.

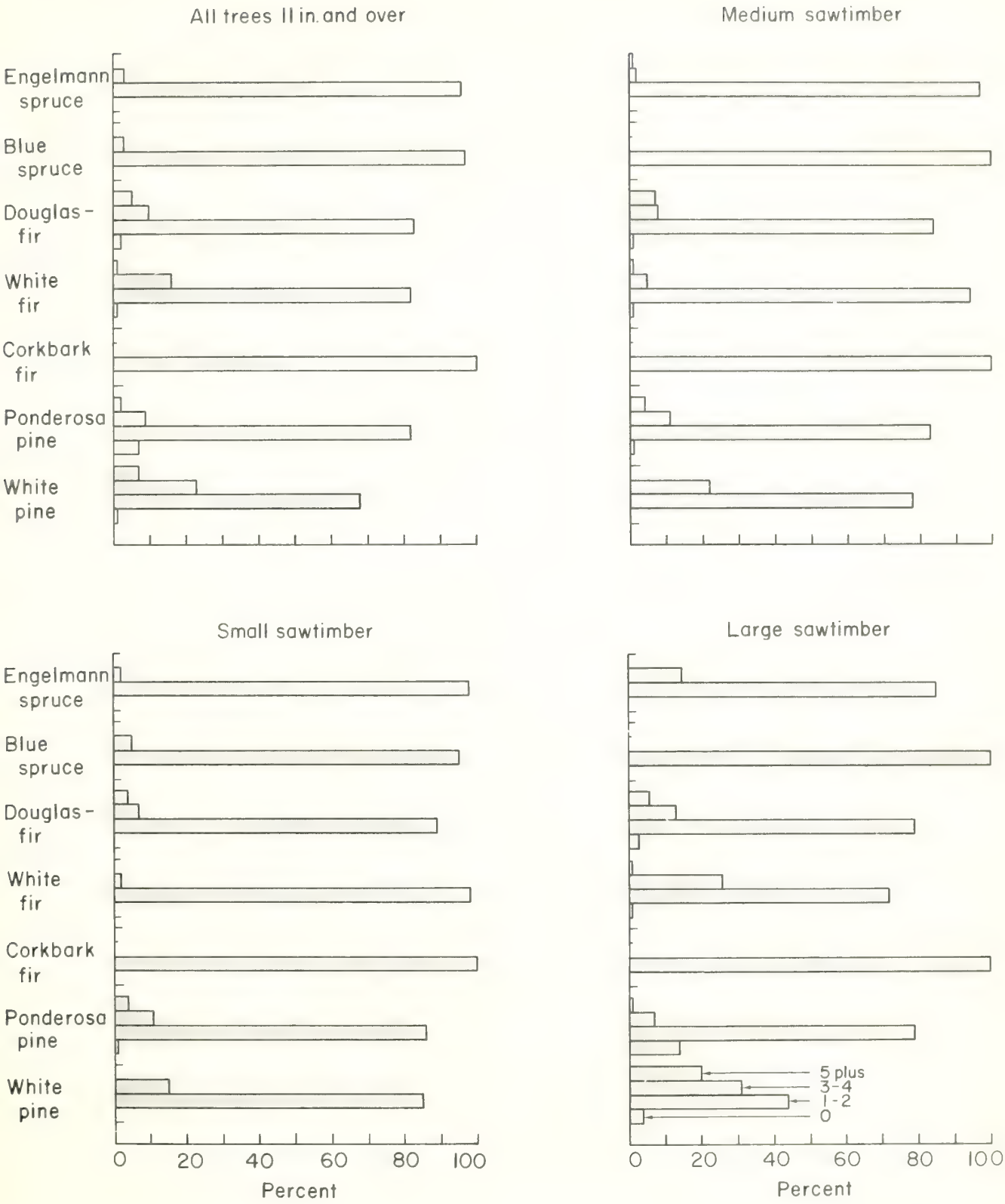

Figure 25.--Percentage of coniferous sawtimber stems in which the maximum knot size in the butt 16-foot log is 0, 1 to 2 inches, 3 to 4 inches, and 5 inches or more.

Embry, Robert S., and Gerald J. Gottfried.
1971. Frequency of stem features affecting quality in Arizona mixed conifers. USDA Forest Serv. Res. Pap. RM-70, 19 p., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

Frequency of occurrence of visual stem features that affect end-product quality and yield is presented by species and size-class. Data were obtained in an overstory inventory of 1,800 acres of mixed conifer forests in the Arizona White Mountains.

Key words: Timber quality, mixed conifer forests.

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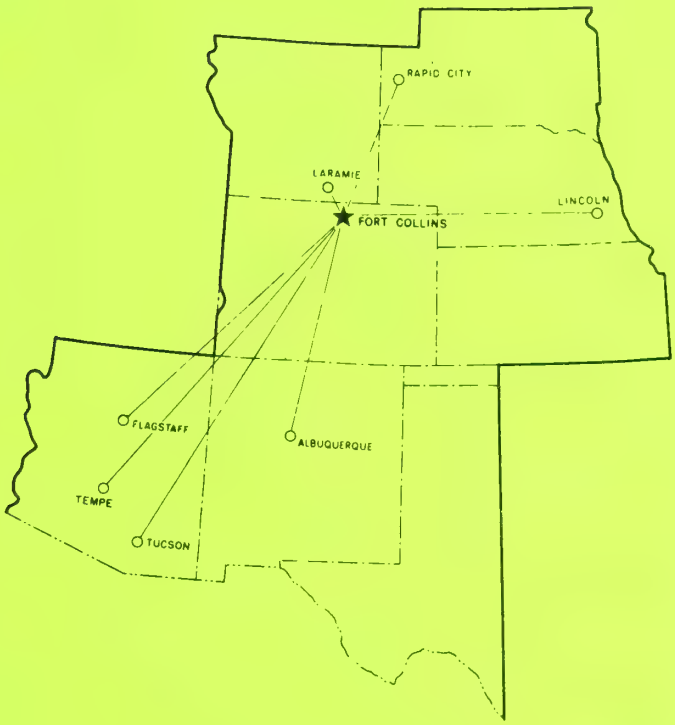
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